Vol. XVI January to December, 1911

JOURNAL

OF THE

WESTERN SOCIETY

OF

ENGINEERS

PAPERS, DISCUSSIONS, ABSTRACTS, PROCEEDINGS

CHICAGO
Published by the Society
1735 Monadnock Block

Subscription Price $3.00 Per Volume
of Ten Numbers

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PRESIDENT, 1911
WESTERN SOCIETY OF ENGINEERS

Journal of the
Western Society of Engineers

VOL. XVI JANUARY, 1911 No. 1

PAINTS AND PIGMENTS.

By A. H. Sabin.*

Presented May 27, 1910.

A great deal of work has been done in the last four or five years in connection with ordinary mixed paints such as are used for house-painting, construction work, bridges, etc., and it occurred to me that a sketch of the work that is being carried on by some of the principal people who are engaged in it, including the American Society for Testing Materials, might interest the members of this Society. For some twenty years I was in the varnish business—manufacturing varnishes—as chemist and director, but at present I am with the National Lead Company, who make white lead and oxides, and lead products in general. They sell white lead to people direct, to paint their houses with, they sell white lead to the makers of mixed paints, so they have no quarrel with them; they manufacture lead sulphate, so they have no protest against that; and they make, of course, red lead, orange lead, litharge, and such materials. I have nothing to do with the business end of it, as I am a laboratory man, but the company has as neutral a position in this whole paint business as anybody can have.

First, I will exhibit some pictures illustrating the manufacture of white lead, for generally the manufacturers of mixed paints start with white lead as a base. Roughly, these paints contain from 40% to 60% of white lead.

Table 1 shows the chemical composition of white lead, which is a mixture of about two-thirds lead carbonate and about one-third lead hydrate,—probably in some kind of an obscure combination, the proportion varying somewhat because of more or less free lead-carbonate.

Table 2 shows the composition of American pig leads, from which it will be seen that the crude lead contains a considerable amount of impure matter. In making white lead it is very important that all traces of silver, tin, bismuth, copper, and antimony should be removed, because those metals are liable to turn the pigment dark when exposed to the weather; so these pig leads are

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*Consulting Chemist National Lead Company.

put through a process of refining,—removing the other metals,—until the lead becomes very pure, probably the purest metal that is known in commerce.

What White Lead is—Chemically!

$2PbCO_3.Pb(OH)_2$

I.

Lead Carbonate	68.91%
Lead Hydrate	31.09
	100.00

II.

Lead	80.12%	
Equivalent to		
Lead Oxide (PbO)		86.31%
Carbonic Acid (CO_2)		11.38
Water (H_2O)		2.31
		100.00

Table 1.

Figure 1 shows the crude materials stacked up where they are received in one of our factories. Portions of the lead which have been cast into round plates, about like a large cooky, but somewhat thinner, are also shown, together with some peculiarly shaped jars,

COMPOSITION OF AMERICAN PIG LEADS.

a — South-East Missouri Undesilverized
b — South-East Missouri Desilverized
c — South-West Missouri Undesilverized
d — Ordinary Common
e — Ordinary Corroding—or Refined

	a	b	c	d	e
Silver	.0070%	.0004%	.0005%	.0005%	.0005%
Arsenic	trace	trace	trace	trace	trace
Antimony	.0030	.0030	.0020	.0100	.0050
Tin	none	none	none	none	none
Bismuth	.0030	.0030	.0030	.0800	.0500
Copper	.0600	.0003	.0190	.0006	.0006
Cadmiun	none	none	none	none	none
Iron	.0015	.0015	.0015	.0015	.0015
Zinc	trace	trace	trace	trace	trace
Cobalt and Nickel	.0080	none	.0018	none	none
Manganese	none	none	none	none	none
Total Impurities	.0825	.0082	.0278	.0926	.0576
Lead	99.9175	99.9818	99.9722	99.9074	99.9424
	100.	100.	100.	100.	100.

Table 2.

in which the plates are placed for corrosion. These plates are called buckles because of their similarity to an old-fashioned shoe-buckle, although they are much larger—four or five inches in diameter. The buckles contain holes and are cast in this shape to get as much surface as possible.

In Fig. 2 is shown where the pigs of lead are put into a kettle, and melted by fire underneath,—a very simple arrangement. The lead runs out through a spout and on to an endless chain. The tops of the links of the chain are moulds, in which the round pieces of lead are cast and carried along, cooling as they go; when they get out to the further part of this endless chain,—that is, to the other pulley,—they are cool enough to be dumped off and taken away. It is a constant, endless process. The buckles are cast in various patterns, differing slightly in proportion, some preferring one and some another. They cannot be made of sheet metal, and they cannot be rolled out, for if they are the corrosion does not take place uniformly.

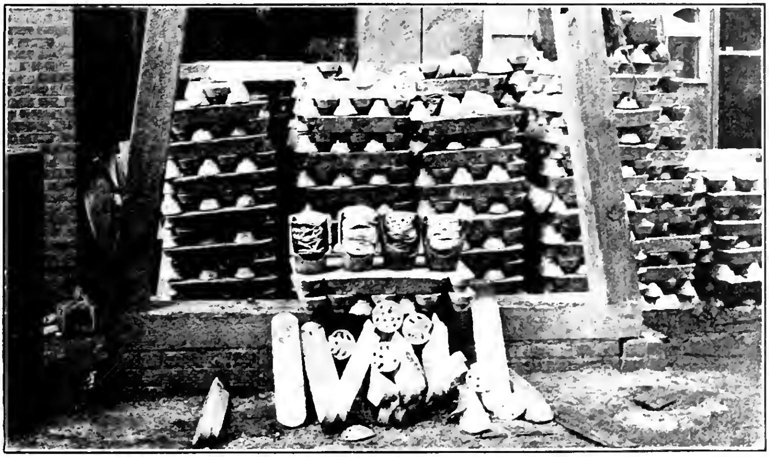

Fig. 1. Pig Lead Stacked Up.

It takes about three or four months to corrode one of the stacks of lead, so that only about three, or possibly (under favorable circumstances) four corrosions are obtained in a year.

Figure 3 is an enlarged view of some of these buckles, and Fig. 4 shows one of the pots in which the corrosion takes place. The pot is made of hard clay, glazed inside—at the bottom especially—and there is a hole in the side, for ventilation. In the bottom—the smaller portion—some weak acetic acid, or vinegar, is placed; then the buckles are laid in until the pot is filled with them, after which it is covered over. These pots are stacked up in fermenting tanbark which generates carbonic acid; the corrosion is

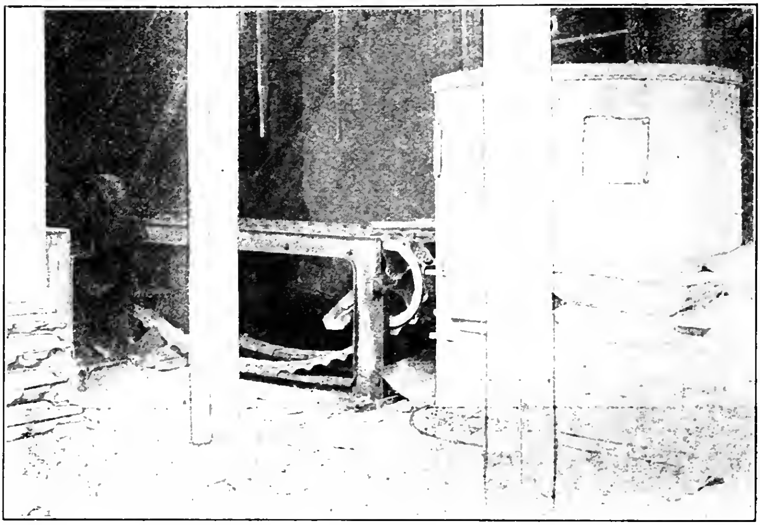

Fig. 2. Melting of Pig Lead.

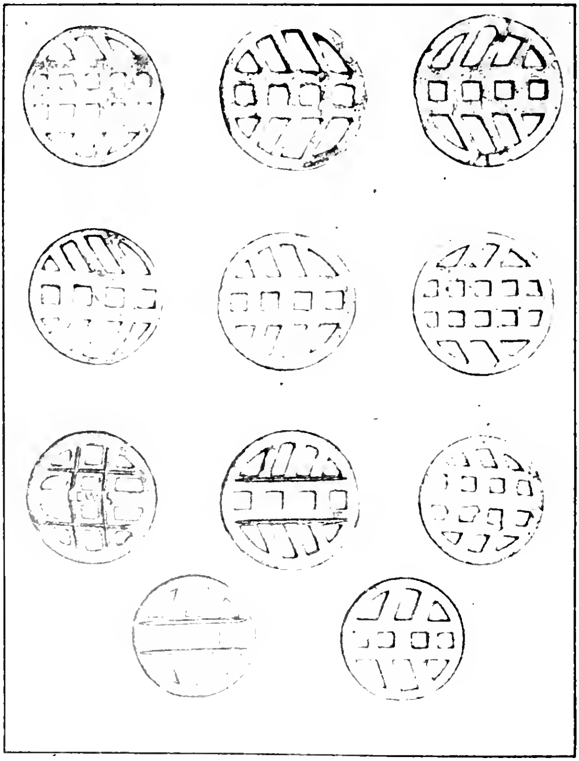

Fig. 3. Buckles.

started by the fumes of the acetic acid, the carbonic acid carrying it on and converting the lead into the carbonate. The hole for ventilation allows the carbonic acid, which is all through the mass of tanbark, to get in freely.

In the construction of one of these stacks of buckles, beginning at the bottom the men put down a bed of tanbark; on that they place a layer of pots, and cover them with boards to keep the dirt out; on top of the boards they place six or eight inches of tanbark, then another layer of pots, another layer of boards, and so on until the space is full. The stack will be 30 ft. or more in height. The men begin at the bottom, and as they build up the pile they board it up around the sides; taking it down they begin, of course, at the top and work on down to the bottom. There is always more or less vapor and carbonic acid forming and it is important that the stack be kept at a certain temperature; by placing a thermometer in a ventilating chimney the operator can know and regulate the temperature in the stack; if it is getting too cool he can close the damper; if it is too warm he induces more ventilation.

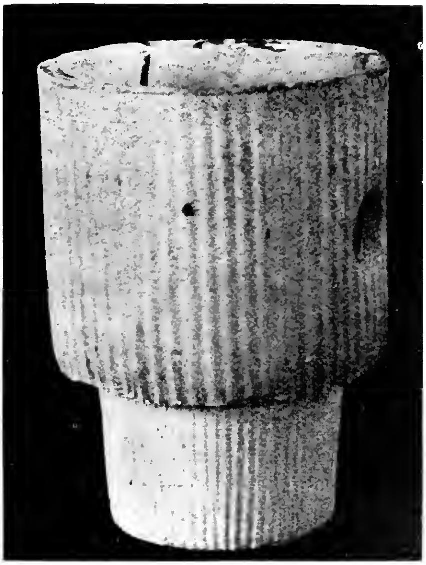

Fig. 4. Corrosion Pot.

Figure 5 shows the filling of a layer of these pots with buckles; boards are piled up on projecting pieces of iron pipe forming supports or brackets, for use in covering the layers of pots.

Figure 6 shows one of the stacks being taken down, and also, when the boards have been taken off of these layers, how white the contents of the pots appear, all converted into white carbonate of lead, or white lead.

When the lead has beeen taken out of the pots, it is removed from the buckles, which are not entirely corroded; anywhere from 20% to 30% of the metallic lead will remain uncorroded. The men formerly scraped off the white lead by hand, but as that was unhealthful work, and lead-poisoning came to be known as a common and serious disease, the manufacturers in this country now do that work by machinery. The contents of the pots are dumped into carts or wheelbarrows and taken away, to be dumped into machines which separate, as well as possible, the white lead from the metallic lead; then the material is put through various processes to clean it; finally the white lead, after being separated from the metallic lead, is put through a mill and ground, with water, to break up the lumps and reduce it to as fine a powder as possible (Fig. 7).

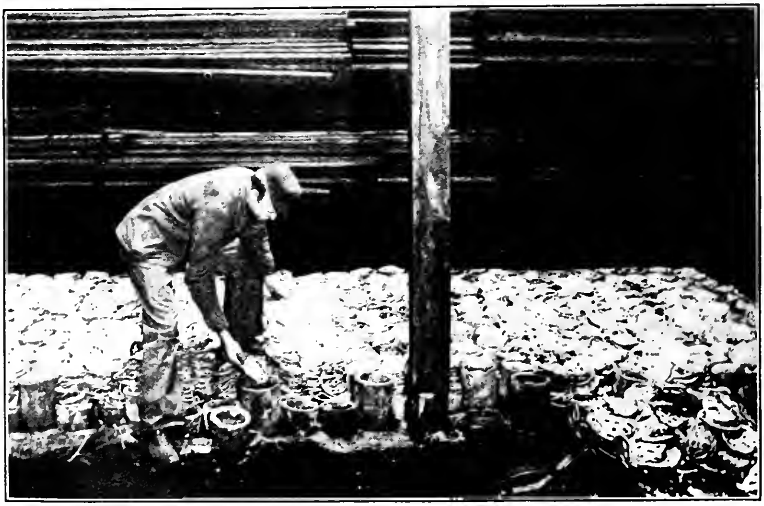

Fig. 5. Filling Pots with Buckles.

The product is then put into what is called a drag-box (Fig. 8)—or something equivalent—to remove the coarse particles which have escaped grinding; not very coarse, but relatively so. At each end of the drag-box is a shaft, one at the bottom,—at the end where the box is deepest,—and one at the other end—above the level of the top. Pulleys on those shafts give motion to a pair of belts to which slats are attached, and as these belts move, the slats scrape the bottom in such a direction that the heavy sediment is scraped upward, where it is pushed out at the upper end, falling into a receptacle from which it is taken back to the mill to be reground.

The ground lead and water are next pumped into the tubs (Fig. 9) which are provided with agitators. As these resemble somewhat the teeth of a rake, they are called rake-tubs. The rakes revolve around the center shaft constantly, and only the heavy metallic lead and the unground particles settle to the bottom; the water, being so agitated with the white lead, removes any acetic acid and dissolves any acetate of lead which may adhere to it. It may be observed that one of these tubs has a trough running around the outside of it; when it is desired to clean a tub, the water and floating lead may be run from one tub through this trough into a third one, and thus the intermediate tub can be put out of service at any time.

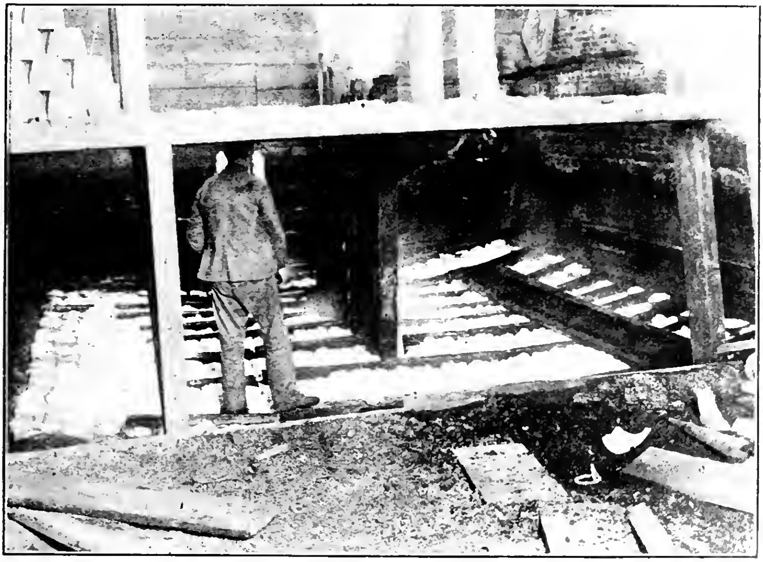

Fig. 6. View of Taken-down Stack Showing the Whiteness of Corroded Lead in the Pots.

After the tub contents have been washed sufficiently, the white lead and water are pumped into the settling tanks and from these it is pumped into large copper drying pans (Fig. 10), which are heated by steam or flue gases; these pans are as long as the room in which they are used, and about a foot deep. When dry, the lead is about five inches deep; it is removed and ground, either dry or in oil.

The lead mills are like any paint mills, but of large size. Lead is sometimes ground in a chaser (Fig. 11), which is a pan several feet in diameter, in which a heavy wheel—usually a stone—rolls round, and as it rolls of course it constantly slips on the bottom.

The especial merit of this machine is that a dry powder can be mixed in it with a minimum amount of oil, and in that way putty and thick pastes can be made. It is an old and well-known type of mill, not economical as regards power, but otherwise efficient; its disadvantage is that it exposes the material to the air, and to floating dust.

Figure 12 shows a piece of laboratory apparatus, invented by Mr. G. W. Thompson, for the purpose of classifying pigments—any sort of pigments—with relation to the size of their particles. It consists of a series of brass cones, beginning with a small one at the top and gradually increasing in size toward the bottom, where the apparatus terminates in a glass funnel. We will put, for example, some white lead in the top cone and by a pump, which is driven by an electric motor, we force a little stream of kerosene oil into that cone,—something which will not act on the pigment at all. As the contents of the cone overflow into the next cone, the coarser particles of the lead sink into the bottom of the upper cone; then in the second cone the next finer particles settle and the remainder of the contents overflow into the third cone, and so on. The last portion runs off through the glass funnel with filter paper in it, and the kerosene oil runs down into the pan at the bottom; from there it is pumped up and the process goes on continuously. Taking, say, something like a half ounce of white lead to start with, by that means we can separate it, in about three or four hours,

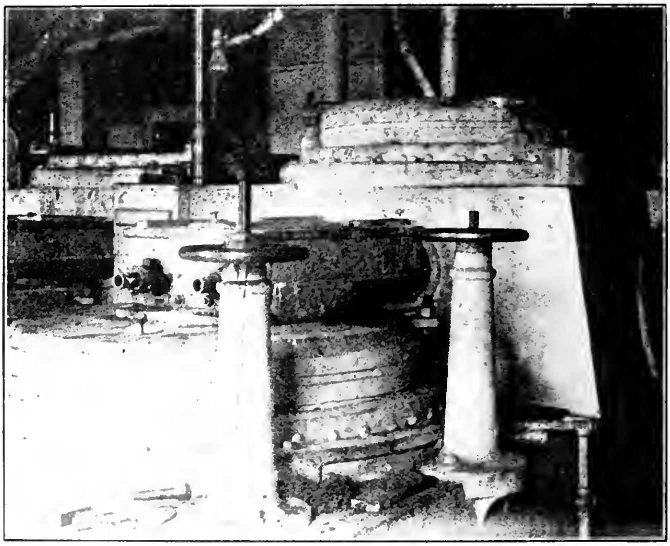

Fig. 7. Grinding Mill for White Lead.

into five portions which differ in coarseness. Obviously, with this apparatus, that separation can be accomplished with any pigment.

We have several of these sets and find them very useful. Each of our factories sends in samples at regular intervals, which are tested to see how fine the material is which is being turned out. It is a great mistake to suppose that pigments are anywhere near the same degree of fineness.

Figure 13 shows some of the largest of these particles greatly magnified (cone 1); but these particles are all on the same scale, averaging about 1/1000 in. in diameter, and show the comparative sizes as they are sorted out by this machine.

Figure 14 shows the particles from cone 2. Again we will see they are fairly uniform in size, indicating that the machine does efficient work. These particles are much smaller than those in cone 1.

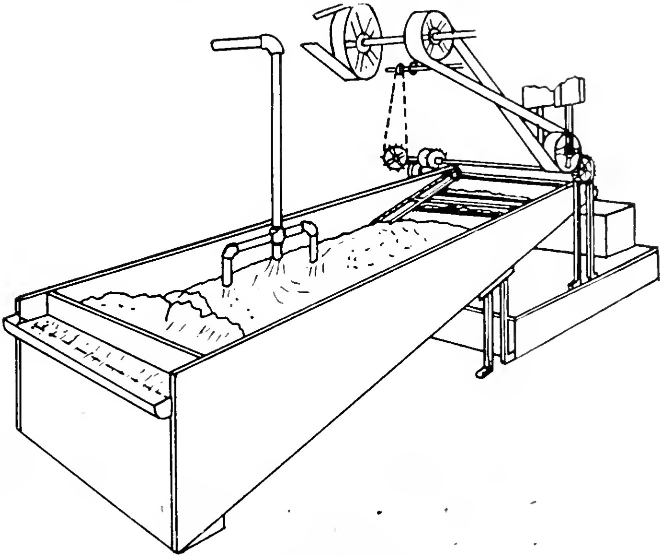

Fig. 8. Drag-box.

Figure 15 shows the particles in cone 3, which are still smaller, some of the finer ones being flat.

Figures 16 and 17 show the particles in the last degrees of fineness.

Of course there is an infinite variety of sizes and all that we can do with such an apparatus is to make a rough assorting.

Table 3 shows the classification made by this machine, and is the average of a number of determinations. In cone 1 we get 3.42% of the sample. In the laboratory, at least, we regard that coarse material as being too coarse to put in paint. If we could get rid of it we would. You will understand that it has all been floated off in the water in the tubs shown, and it has all been floated through the finest bolting-cloth that can be bought—floated through it wet—and yet we get about 3½% of pieces which are about 1/1000 in. in diameter. In cone 2 we get about twice as much material, or 6%; in cone 3, about 6⅔%; in cone 4, 8¾%. Then of the very

CLASSIFICATION TEST ON DUTCH PROCESS WHITE LEAD.

	Diameter of Particles.		%
In Cone 1	a		3.42
" " 2	$\frac{a}{4}$		6.41
" " 3	$\frac{a}{16}$		6.61
" " 4	$\frac{a}{64}$		8.72
Finer than 4	$\frac{a}{x}$ $x > 64$	by diff.	74.84
			100.

Table 3.

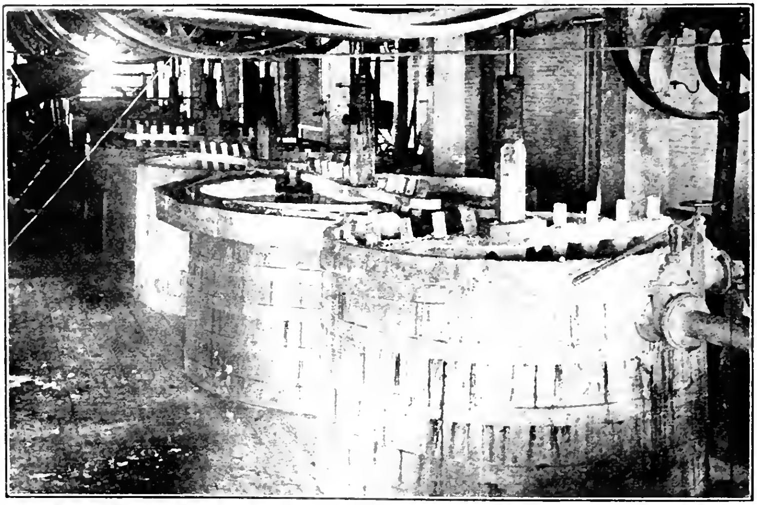

Fig. 9. Agitating Tubs.

fine material there will remain about 74% which was caught in the filter paper; most of the lead—three-fourths or four-fifths of it—is that very fine material; so white lead, on the whole, is an extremely fine pigment, although there are some coarse particles in it.

I have given simply a rough outline of the way in which what is known as the Dutch process white lead (which amounts to four-fifths or perhaps nine-tenths of all the lead pigment that is made) is manufactured. There are some quick processes which make excellent products, but they have not yet displaced the old, slow-corroding process.

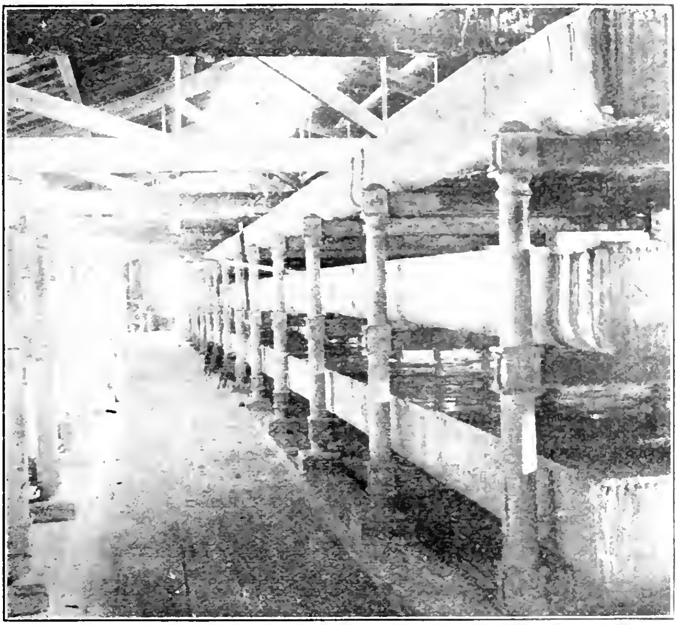

Fig. 10. Copper Drying Pans.

Litharge is made in a shallow reverberatory furnace, the pot of which is shaped about like an ordinary coffee-saucer. The hearth is several feet in diameter and is heated by flames passing over it. Workmen throw in the pigs of metallic lead, and when melted the mass is stirred with a long-handled iron hoe to bring fresh portions to the air. There is a large door in the front of the furnace which is open constantly so that air from outside can get in freely to oxidize the lead. In about a day and a half the lead will all be oxidized into litharge; then it is hauled out and is ready for sale as litharge for such purposes as litharge is used. Sometimes it is ground, to meet certain requirements.

To make red lead, litharge is put into a similar furnace and heated at a lower temperature, when it takes up more oxygen. That might at first seem remarkable, but it is really a normal condition, because with almost any of the metallic peroxides, if they are heated strongly they will give off part of their oxygen; for example, we can make oxygen by heating the peroxide of manganese. So it is only natural that if we make a lead oxide and heat it at a lower temperature it will take up more oxygen. The litharge is made at a temperature of about 1600° F. and the red lead at about 900° F. The litharge is present in little grains; the oxygen is taken up on the outside of those grains and gradually works to the middle of them, the litharge thus becoming peroxidized all through. Of course that operation will be more rapid if the litharge is in fine particles; as a matter of fact, after allowing the litharge to cool, we dry grind it and make the particles very fine, in that way getting a more nearly perfect peroxide of lead. Red lead always contains a little litharge,—twenty years ago it was not uncommon to find as high as 45%,—but it can now be obtained, made in this way, containing not more than 5%. A great deal of red lead contains not over 20% of litharge, and is what is called 80% red lead.

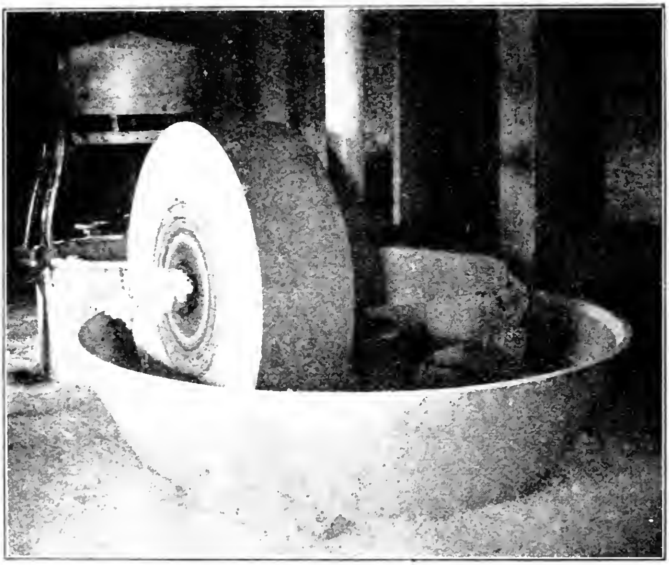

Fig. 11. Chaser.

You are all undoubtedly familiar with the fact that red lead has a tendency, when mixed with oil, to set like a cement. That is because of the presence of litharge, and if we have an 80% red lead, it will stand, when mixed with oil, for a long time without setting: it will settle to the bottom but can be stirred up and made all right again. I was talking recently with the superintendent of one of the plants in Chicago, and he told me that he was using some red lead paint on his plant. He was thoroughly satisfied that to get good results from it one must mix it up and allow it to stand at least a full day; then stir it up again. It was his opinion that this paint, when allowed to stand, did not have the tendency to run that it did if used when mixed up fresh. He also said he believed that 30 lb. of lead to the gallon of oil, if allowed to stand and age, was as much as could be used. A common formula is 33 lb. of lead to the gallon of oil. I know that red lead containing as high as 90 or 95% of the peroxide will keep for months without any tendency to form a cement or set, and orange mineral, called sometimes orange lead (which is a pure lead made by roasting dry white lead and does not contain any appreciable amount of litharge), will keep for a year in oil. Some of the ready-mixed red lead that is sold is nothing but orange mineral ground in linseed oil.

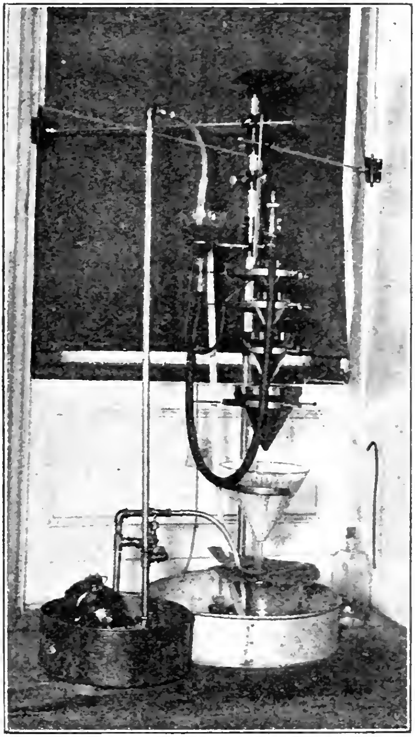

Fig. 12. Apparatus for Classifying Pigments, According to Fineness.

Now I want to tell you something in regard to recent paint legislation. About five years ago Professor Ladd, of the State Agricultural College in North Dakota, who was State Food Commissioner, got the idea that it would be a good scheme to have the inspection and sale of paint placed under restrictions similar to those of food, and he drew up a law providing that paints should bear labels showing their exact composition. That is, roughly, what it amounted to. The matter created a good deal of discussion and the law was opposed, was fought through the courts, and has been upheld by the federal courts. The law is accepted as valid and many of the western and some of the eastern states have enacted what is practically that North Dakota law. A law is now pending before Congress, without any great probability of being passed, providing for the same thing,—a national pure-paint law. The people who have opposed this have done so on the ground that they do not want to have their formulæ at the mercy of their competitors. That is an intelligible thing, of course, but Professor Ladd was able to show that in North Dakota there was being sold what purported to be pure white lead and pure linseed oil that did not contain any white lead or any linseed oil, and from such facts, as a choice of two evils it would be a less one to have a labeling law.

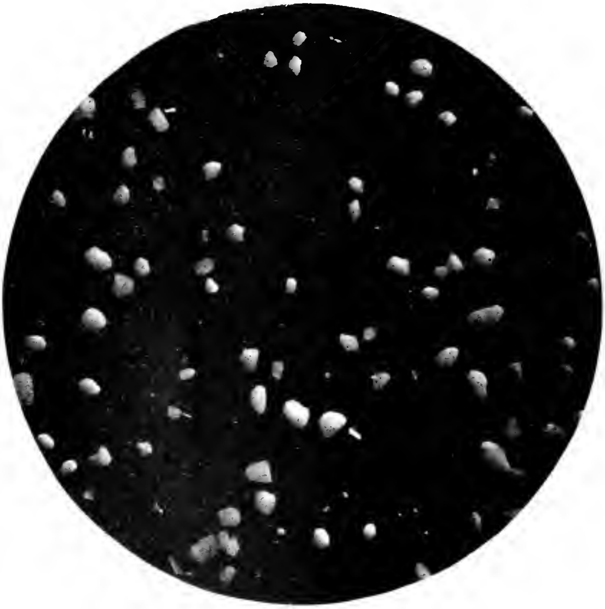

Fig. 13. Pigment Particles Greatly Magnified.

In 1906 Professor Ladd built, out in the college grounds, what has become quite a famous fence, about 7 ft. high and 75 ft. long. It was made of solid boards, much like a bill-board, and on one side he covered half of it with white pine and half with Oregon cedar clapboards. He painted both sides of this fence with a large number of paints of all sorts, which he bought in the open market in North Dakota. That fence has been standing now four years. I have just returned from a trip I made to look at it. Some of the panels look almost as though they might never have been painted, while others are in excellent condition. The panels painted with iron oxide look as if they might have been painted last fall; they are almost perfect. It is astonishing how that paint has endured. Most of the freight cars in this country are painted with iron oxide. On an iron bridge or anything of that sort, however, I believe iron oxide is not so durable.

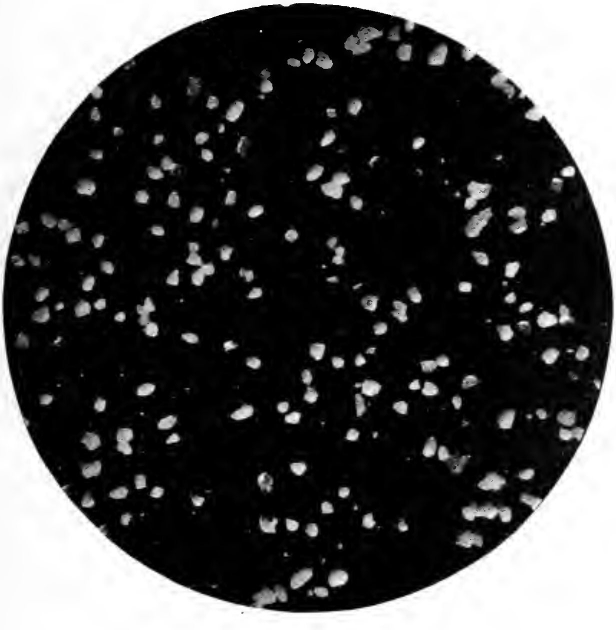

Fig. 14. Pigment Particles, of Smaller Sizes.

The Paint Manufacturers' Association and the National Lead Company contributed money for test-fences in 1907 and 1908, which were built at their expense and painted with paints prepared by them, except that some panels were painted with white lead and white zinc given by the makers of these pigments. The 1908 fence has not yet been built two years, and of course the paint has not deteriorated enough to show much change, while the 1907 fence shows quite a little change.

As a matter of fact, those fences have apparently shown results to different observers according to what they wanted to see. Quite a number of people have been to look at the 1906 fence and several reports have been made on it. My own impression is that the old-fashioned white lead has endured better than anything else. The sulphate of lead has worn off a good deal but it looks very well. We know that it is said that white lead chalks and that the surface of it seems to lose its oil, when it will brush off. About the second year it chalks a good deal; the third year there is little indication of this trouble; the fourth year and after that, none at all. The sulphate of lead is late in starting to chalk, but after it once begins it does not seem to stop. Chalking is not as serious a matter as many people think. It is objectionable, of course, but as a matter of fact if there was not some paint there it would not brush off, and it is only those paints which have a good deal of opacity and body which do chalk. There are some excellent paints, too, which never chalk.

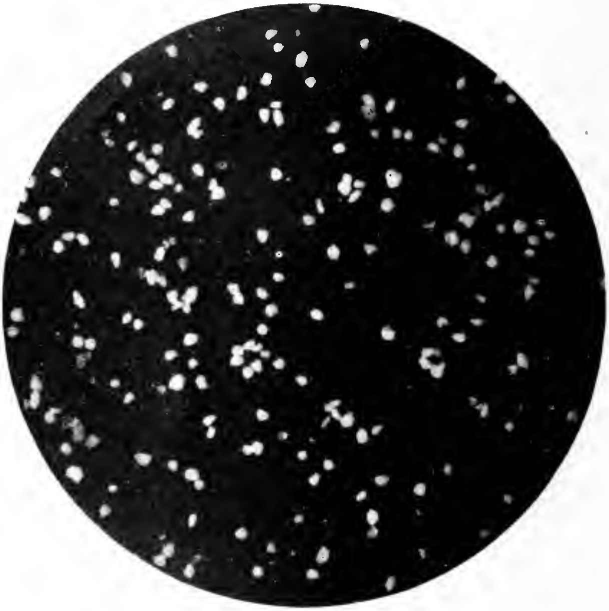

Fig. 15. Pigment Particles, Still Smaller Sizes.

A good deal has been said about active pigments and inert pigments, and it is generally believed by those who use the terms that white lead and white zinc are active pigments; that is to say, they have action upon the oil and combine with it. It is my belief that they do combine with the oil to some extent; but I will ask you to observe that so far as activity is concerned it is as yet a belief and not a scientifically known fact, and I hope we are going to find out in the course of a few years whether that is true or not. The paint manufacturers say that lead and zinc are greatly improved by the addition of some inert pigments, and the most common thing that is added—especially to white paints—is barytes. Barytes is the natural sulphate of barium ground to a fine powder. Undoubtedly many of those who use it believe that it is a valuable ingredient, but personally I have seen no evidence that leads me to believe that. Many of the paint men speak of carbonate of lime,—that is, whiting, ground chalk,—as an inert pigment, but certainly it is not; carbonate of lime will attack the oil in a paint. Theoretically it ought to do it and practically it does, so I would not regard carbonate of lime as being an inert pigment. Some of the silicates, such as asbestine,—they are in various rocks of the hornblende class,—ground up, are used a good deal; they apparently have no effect upon oil and are probably good materials in paint. Silica itself is used a great deal and it was highly thought of by the late Dr. Dudley as a paint material,—that is, mixed in with lead

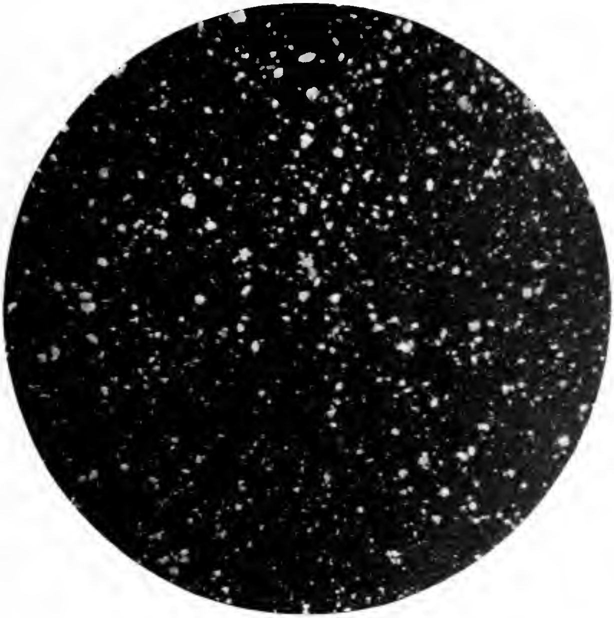

Fig. 16. Pigment Particles, Extremely Fine.

or zinc, for that has no effect on oil. It is assumed that these inert pigments are all alike in their action, but I do not think that is true. For example, the oxide of iron that I spoke of having seen, everybody would class as an inert pigment. That has lasted very well. A barytes or silica coating on a sample board will not last two years; it all goes to pieces; so there is a difference. Each one of those pigments must have its merits determined by itself. I am inclined to think we shall find that surface-attraction between the oil and the pigment has a good deal to do with the matter. We know that some solids seem to have an attraction for some liquids. For example, glass attracts water. If we place a capillary tube in water, the water will run up in the tube. If we place that same tube in mercury, the mercury will be depressed. Mercury has no attraction for the glass. If the glass were powdered up, it will be easily understood that the water would stick to it with a great deal of tenacity, whereas mercury would not penetrate it at all. That is a matter of surface-attraction between the two things. Undoubtedly oil has a similar relation to different substances, and I have an idea we shall find that those solids between which and oil there is an attraction form good pigments, but I am not certain. I expect to make some experiments along this line.

Fig. 17. Pigment Particles in Last Degrees of Fineness.

Painting is for the purpose of protecting, or to secure a decorative effect on, the surface that is painted, and after a few years that surface must be repainted in order to secure permanence of that protection or effect. If the paint that is put on the first time has to be scraped off, it costs a good deal and probably leaves the surface in poor condition; whereas if the paint has worn off from the surface and there is still a good adhesion to the wood underneath (or iron, if it is iron) one can clean off with a stiff brush—a wire brush or something of that sort—what is loose, and still have a surface that will be good to paint on. That is the best paint, even though it may not last as long by 15% or 20% as the other one. So a paint test is never complete until we are through painting, and we cannot reasonably expect to get a result under four or five years, if the painting has been properly done.

The Paint Manufacturers' Association built a fence something like that which I have described at Atlantic City a couple of years ago, and I, as a member of Committee E of the American Society for Testing Materials, was one of the inspecting committee to look at it. (We had nothing to do with the fence, you understand, and in no way are we standing sponsors for that fence. We simply agreed to go down and inspect it occasionally.) We went there at the time the panels were being painted. The fence was not made out of clapboards but was a support for movable panels, which were painted in a shed and after being painted were attached by screws to the fence. It was done in the winter-time, when there was snow on the ground. All painters are agreed that painting should be done when the temperature is not lower than 50°, and preferably at about 70° F. The building was a long closed shed, made of one-inch boards, and had some windows in it. There was a little stove in the middle of the building, but the temperature was so low that the members of the committee (there were eight or ten) stood around with their overcoats, hats, and gloves on as long as they could endure it and then departed in search of something warm. It was no place to do painting. The first panel was painted and placed against the wall; then another one was painted and placed near the first, with a little support as a slight separation; another one was painted and placed against the second, and so on, until the panels were piled up nearly half way into the room. The building being a long one the panels were piled along the wall, leaving a gangway through the middle so that one could walk through. No paint under the most favorable conditions of weather would dry normally in such a stack as that, as the air did not have any chance to circulate properly among the panels. Then, too, the boards were a poor quality of timber. They had been kiln-dried and after being sent to Atlantic City they were stored in that vapor saturated atmosphere until they got so damp that the water could almost be squeezed out of them. The paints were prepared by paint manufacturers, according to formulæ which they devised, and were sent there in proper condition to be used, but on account of the low temperature they were so thick they could not be applied in the condition in which they were sent there; the master painter had to thin each one of them with turpentine and no two of them were alike. On the whole, the test was very unsatisfactory.

That fence has now been standing two years and we made our last inspection of it a few weeks ago. About the first of this month the best panel on that fence was very bad. Atlantic City is full of wooden houses, most of which are painted white, and to my knowledge they are not painted on an average more than once in five or six years, and it would be difficult to find a house there that does not look better than the best of those panels that have been there only two years. I do not think any serious value can be attached to the results from that Atlantic City fence. They are not so much misleading as they do not lead anywhere. They are of no value.

I do not wish to discourage anybody from making tests. Those people will make more tests, and the next test-fence will doubtless be built differently. The American Society for Testing Materials is hoping to have a fence of its own this year and will put on about two dozen different kinds of paint,—all white. What it is going to try to find out definitely is the real value of some of the standard mixtures; for example, mixtures of white lead and white zinc; whether white lead is better by itself or with a mixture of zinc; whether zinc is better by itself or in a mixture with lead. Mixtures of zinc and lead with barytes, with silica, with asbestine, and such materials will be used in an endeavor to find out what the effect of mixing really is.

Those are things that we want to find out, and all the present agitation in connection with paint will doubtless bring about good results. It is going to incite the chemists and paint men all over the country to make more careful and more scientific experiments

Discussion.

Mr. M. H. Dance, M. W. S. E.: I would like to hear something about the application of white lead and zinc on iron. Most of my work has been in connection with iron and not with wood.

Mr. E. N. Layfield, M. W. S. E.: I do not understand why it is such a difficult matter to determine whether oil in drying shrinks or expands. I make no pretense of being a paint expert, but it seems as if it would be an easy matter to simply stick a knife in and see whether it opens up or whether it has the opposite tendency. Of course, I realize that people who have made a life-study of the subject know why this tendency is not so evident, and I think it would be of interest to have this explained.

Last year we had an address from Mr. R. S. Perry, of Philadelphia, in which he referred to the steel fence at Atlantic City. Was that fence for the purpose of testing paint on metal, and was it as unsatisfactory as the wooden fence?

Mr. Sabin: The steel fence was for the purpose of testing paint on metal. That fence has been built only a year, however, and results have not yet been obtained from it, but it looks very well, most of it. The Paint Manufacturers' Association built both the steel and wooden fences.

Mr. Ernest McCullough, M. W. S. E.: I am anxious to hear something about the protection of metal by paint, and I had hoped that Mr. Sabin would allude to the Pittsburg fence, which I believe is made of metal. I saw that fence last year, and am wondering if it was put up in a better way than the Atlantic City fence.

The covering of wood does not interest me as much as the protection of iron and steel. The point brought up in regard to the action of oil and pigments, or the combination, was one that I heard discussed a few months ago by some parties who stated that there is no absolute certainty that linseed oil is the very best vehicle for certain pigments, and that there might possibly be a combination made of some other pigment with some other medium that would give about as good results as the best lead and the best linseed oil, prepared in the most scientific way. These gentlemen believed that the North Dakota fence would bring out that fact. They were prepared to admit that some paints were made without either white lead or linseed oil, although they had been advertised because of—as they expressed it—the existing prejudice in favor of paints ground in linseed oil; they believed that time would show that these paints were just as good as those ground in linseed oil. The question came up as to whether or not there might be a repulsion between the pigment and the vehicle in which it was ground. They spoke about oxide of iron, as if almost any kind of oil could be used as a vehicle if laid on wood; of course, in the case of metal, it is a different matter.

Mr. Sabin: The Pittsburg fence is made of wood. That has been built since the Atlantic City fence, and I have not seen it.

Mr. Julius F. Werlich, M. W. S. E.: The question that appeals strongly to all engineers is the use of paint on metal,—especially steel,—and I am hoping that Mr. Sabin will give us his opinion as to the value of red lead used as a protection to steel.

Mr. Bertrand G. Jamieson, M. W. S. E.: I would like to add to the last request by asking for information in regard to fire-proof paint.

Mr. William Artingstall, M. W. S. E.: I suppose I am in the position of almost all engineers; if the man we are doing the work for wants black paint we give him graphite; if he wants red, we give him red lead, and after that we lose all interest in the matter. That has been my experience, except in one or two cases where we had some very wet girders on which we were trying some paint; also in the case of some cement paints, which are merely cement washes, but this work has not progressed far enough to warrant any remarks in that connection.

I believe that the point which is usually overlooked by many engineers is the necessity of having the metal absolutely clean before paint of any kind is applied. We may specify that the metal "shall be thoroughly cleaned with wire brushes and all rust or scale removed," and then put a young inspector in the field who is probably in the office figuring a little cost data at the time the painters are busy on the structure, and neither he nor the engineer knows whether the paint has been put on a clean surface or not.

The inspector should not be the only one blamed for poor painting. I believe that we specify too heavy a first coat (I refer now to a red lead paint), and it is my opinion that if for the first coat we will use a paint of, say, 18 to 20 lb. of red lead per gallon of oil, and increase the amount of lead to 23 or 25 lb. for the second coat, and, if a third coat is required, increase the lead to 26 or 27 lb., we will get a far better piece of work than if a heavy paint is used for all coats. Where a first coat is of heavy consistency, it does not adhere well to the steel, but can be stripped off, leaving the steel practically clean. Where a light-weight first coat is used, however, this cannot be done.

If we remember that probably the worst test to which paint can be subjected is around the bulkheads in the ocean-going vessels, and profit by the experience of the "old line companies," we will apply a first coat containing just sufficient lead to "keep the oil from running." As a matter of interest I might recite a rule given me some time ago by the Master Painter for one of the largest ocean freighters:

1st coat—14 lb. to 16 lb. red lead to the gallon of boiled linseed oil.
2nd " —18 lb. to 20 lb. red lead to the gallon of boiled linseed oil.
3rd " —22 lb. to 24 lb. red lead to the gallon of boiled linseed oil.

Mr. Carlton R. Dart, M. W. S. E.: I am very glad to be here this evening, as I have obtained some valuable information on the subject of paint.

The subject of the protection of steel has not been discussed with the exception of a few remarks regarding red lead and orange mineral. Personally I do not like red lead as a structural paint because it is an active pigment and should be applied very quickly after mixing. If it is made into a ready-mixed paint it seems to me that regardless of what it is loaded, the set cannot be put off a great while unless a pure red lead or orange mineral is used. I understand from what Mr. Sabin says that orange mineral is an inert pigment, or nearly so, and there is a question, therefore, whether it is better than any other inert pigment. I have never been satisfied on that point, as it has seemed to me that one peculiar value possessed by red lead lies mainly in its cementing properties, and if the paint is not applied soon after mixing, a more or less chemical change will occur. Whether it is allowed to settle and cake, or whether it is kept stirred and held up by loading, it seems to me that its value is largely lost after a comparatively short period of time. From a practical standpoint I never use red lead when I can avoid doing so, because, while specifications usually call for 33 lb. or 30 lb. per gallon of oil, 25 lb. is generally sufficient, and with that amount there is some question whether it is properly mixed when it goes on the steel. It certainly is not unless there is an inspector over almost every painter.

I have used sulphate of lead, or natural blue lead, which seems to give very good results. It is practically an inert pigment, is very finely divided, and seems to make as good a pigment as almost any other material.

I would like to inquire as to the difference in cost of red lead and orange mineral. I should imagine that orange mineral is considerably more expensive as it is derived from the corroded lead or from a portion of it. I would like also to inquire what Mr. Sabin's opinion is as to the value of orange mineral and red lead as a pigment.

In regard to the white lead, I understand that the process described by Mr. Sabin is the old Dutch process, but I think the newer processes are not used extensively.

A point has been made regarding the difference in color of coats. I think those who have much to do with painting will appreciate the value of different colors for successive coats. When painting is performed by the ordinary paint contractor, and even by one's own men, especially in case of the glossy paints, it is difficult sometimes, especially in a dim light, to tell whether material has been coated twice or once.

I had occasion some years ago to examine a series of elevated structures in this city, painted with a number of different kinds of paint, and the impression I received was that much depends upon the conditions of application. As far as I noticed, the oxide of iron paint was as good as any of them. Some of the structures must have been painted under unfavorable conditions,—dampness or cold,—and some of the paints that one would think would last the best were among the poorest. The Johnson iron oxide seemed to wear as well as any of the paints.

Mr. Sabin: Referring to the new processes, The Carter White Lead Co. has a large plant in Chicago, one in Omaha, and another in Detroit, all of which are successful; but its output does not amount to a very large proportion of the total amount of lead paint that is made.

Mr. Layfield: I am much interested in what Mr. Sabin has told us about the removal of paint in preparing for other coats, because I have heard a great deal about the hard work expended in burning off three or four coats of paint that had been caked on for three or four years and was badly cracked. That is an important question, and any information we can get in regard to what causes that, and the remedy will be valuable to us.

Mr. George H. Tinker: I will ask the speaker if he will not give us an opinion or suggestion as to the value of mixing lamp black with red lead, and what the effect of it is in different proportions. I am also interested to know the nature of the action that is called the setting of red lead,—whether it is a chemical action, whether it is a drying out, or whether the action is similar to the setting of Portland cement.

I can confirm what a previous speaker said about the value of iron oxide on steel. I was interested some time ago in a series of tests of a large number of different kinds of paint on steel, and it was an open question which showed the better results,—iron oxide or red lead. We tried a great many different proportions of lead,—all the way from fourteen pounds to thirty,—several mixtures of red lead and lampblack, and several iron oxide paints. The final conclusion seemed to be that the red lead paints were somewhat superior to the iron oxides under the same circumstances, but the iron-oxide paints did make a good showing in this series of tests. From the standpoint of one interested in steel, and also in railroad work, the question that particularly interests me in connection with the protection of steel is not the ordinary weather-exposure (in fact there are plenty of paints on the market which give very good protection against ordinary weather exposure), but what I would like to find is a paint that will protect against salt-water brine. If the speaker can give any information on the subject I should like to have it.

Mr. Layfield: Some information, also, in regard to protection against locomotive gases, would be of interest.

Mr. Charles K. Mohler, M. W. S. E.: Some of those present must have had experience with different kinds of paint that they can tell us about. Graphite was largely exploited a number of years ago, but it seems to have lost favor to a certain extent. About four years ago I was engaged in making inspections of bridges and structures in Pittsburg, and examined a total of about 500—all kinds and conditions—and many were in a very bad condition as far as corrosion was concerned. Atmospheric conditions are about as bad in Pittsburg as any place in the country, with the possible exception of localities near the sea. The corrosion of steel structures is very marked in the vicinity of blast furnaces and steel plants. They rust in a few years, so that the paint is as good as gone. On some structures that were painted with graphite and which have been erected not over three or four years, the paint seemed to be of very little value, and the structures were not in much better condition than if they had not been painted at all. In other cases the graphite paint seemed to be giving fair results. The results from iron oxide paint seemed to be about as good as from any ordinary paint, and I think the criticisms made in reference to it were not so fully justified as claimed. When the oxide is mixed with oil it seems to form a practically inert paint. At that time I undertook to investigate and get what literature I could from the different manufacturers and also statements on the different metal coatings, but I never followed it out to a final conclusion. There were quite a number who made special claims for a durable and satisfactory covering.

There is one class of covering that has not been mentioned here which is sometimes used on metal. One firm had issued some literature and claimed to have produced a varnish that was practically impervious, was very adherent, and would give better results than could be had from paint. I have never seen any of that varnish used, and so cannot say what the results are. I should like to know if the speaker has anything to say on that subject, as I understand at one time he was engaged in the manufacture of varnish.

Mr. Bement: The matter of resistance of acid is a problem distinct from that of moisture, and it is something about which Mr. Sabin may possibly say something.

Mr. Tinker: I would ask why the imported French zincs seem to be a superior white to domestic zincs.

Mr. McCullough: We have a French process zinc made in America that is just as good if not better than any that are imported.

Mr. Layfield: I shall be glad to have Mr. Sabin tell us if there is any peculiar condition that limits the production of linseed oil and raises its price? What are the restrictions as to territory or climate?

Mr. Sabin: That is a very interesting point and a very pertinent question. Flax at present is grown on land that has just been broken up, or sod land. It grows in climates where wheat can be raised. For example, our great supplies come from Minnesota and Dakota. Two successive crops of flax can be raised on the same land. Then the land ceases to produce flax. The bacteriologists say that the land gets full of some kind of a fungus which attacks the roots of a flax plant and flax will not grow there. Corn, or clover, or wheat, can be raised on that land, but flax cannot be raised there for a good many years. That is what restricts the production of flax. At the present high prices of oil it will be seen that flax is now a much more profitable thing to raise than wheat. This high price of oil I hope will stimulate the Agricultural Experiment Stations and the Bureau of Agriculture in Washington to find out the cause and cure of that flax disease. It is a disease of the land, apparently; this fungus or these bacteria—whatever they are—get into the soil and stay there. If they can get rid of those conditions—if they can get some variety of flax that will be immune from them—then any amount of flax can be raised, because there is plenty of land, as far as climate is concerned, where it can be raised. We are getting our flaxseed right now from Argentine, and I think it is not quite so good as the American seed, but it will probably be only a question of time when that flax disease will be encountered in Argentine as well as here, and that is what causes the high price of flaxseed. The supply is growing less and the demand greater; there is no artificial stimulation of price, I know. In Canada there is probably more opportunity to raise flaxseed than in this country, because there is a great deal more new land, but the same conditions are encountered there as here. The idea of crop rotation has been tried,—that is, planting flax one year and something else the next year,—but it seems to take a long time to get that fungus out of the ground.

Mr. McCullough: In the north of Ireland, where so much flax is grown for linen, flax is planted only one year in seven.

Mr. Sabin: The rotation idea is followed until they get a turf or sod. The grass seems to kill the fungus. Then that is broken up and another crop of flax is obtained.

Mr. McCullough: Mr. Sabin referred to the rust inhibitors and stimulators. I will ask him if he believes in the electrolytic theory of corrosion?

Mr. Sabin: Yes, surely.

Mr. McCullough: The rust stimulators in nearly all cases seem to be the most perfect paints, so far as integrity of surface goes, and the problem seems to be to get a good rust inhibitor that will combine properly with the vehicle, isn't that it? In other words the stimulators do combine to the very best extent with any vehicle with which they have been tried, but the difficulty seems to be to get a proper vehicle for the inhibitors. Then the question of surface-tension arises.

Mr. Sabin: Yes. In order to have rust the air or the water must get to the surface of the iron, and if you secure a paint that will keep that out,—well and good,—but if you do not get a paint that will keep that out it makes no difference whether it is an inhibitor or a stimulator, you will have rust there. The fact is the particles of pigment in the paint are all surrounded by a non-conducting layer of dry linseed oil, and have little chance to change their chemical nature. With a substance that we know all about,—like white lead, for example,—we can figure out exactly that in any film of paint, the ultimate particles of white lead are separated from one another in every direction by more than one-half of their own diameter.

Mr. McCullough: I should judge that it is really lack of elbow grease in most cases.

Mr. H. J. Wagner: I will ask Mr. Sabin if he has had any experience with asphalt as a base for steel protection?

Mr. Sabin: Indeed I have and have been selling it for ten years. As I have told you, the trouble with varnish for paint purposes for structural work is that it is difficult to apply. The asphalt materials all make varnishes and those asphaltic varnishes can be easily applied in hot weather; but when the weather is cool or cold, they are difficult to apply, and consequently the varnishes are not correctly applied. That is the great objection to those materials. If the asphalt varnishes are well made they will give splendid results if properly used.

Mr. Wagner: Do you think that the difficulty in the use of an asphalt base in cold weather is on account of its rapid thickening?

Mr. Sabin: Yes, that is the reason.

Mr. Wagner: It is due to the natural oil—the asphaltic oil—is it not?

Mr. Sabin: Well, an asphaltum can be obtained, as gilsonite, that is totally free from any oily matter.

Mr. Wagner: What is the reason of the clogging up, the difficulty of working it?

Mr. Sabin: All varnishes do that. Those asphalts are mineral resins and all resinous compounds containing oil do that, but I do not know why.

Mr. McCullough: What about paraffine?

Mr. Sabin: We are talking about asphalt, not paraffine. As far as I know paraffine is not used for any such purpose.

Mr. McCullough: No, but I mean an ordinary commercial asphaltic paint with paraffine or asphaltic flux. Would it make any difference in the thickening up, whether it is made from a petroleum residue or not?

Mr. Sabin: No, it doesn't make any practical difference.

CLOSURE.

Mr. Sabin: I shall endeavor to answer some of the questions that have been asked.

French zinc is made by burning metallic zinc, and American zinc is made by burning the ore of zinc. French zinc is made in this country and American zinc is made in France,—both are made in each country. From the metallic zinc a little purer oxide is obtained and it is a little whiter.

The chalking of white lead is due to the lead and not to anything else.

Of course the oil is the binder. Linseed oil is a vehicle that is used in most paints.

I am thoroughly convinced that a varnish paint can be made which will outlast any oil paint, and I think that most of the best manufacturers believe it. For example, in the recent edition of

Houston Lowe's book he says, while he does not make such paints, a varnish paint can be made that will outlast any oil paint. I do not mean that all varnishes will outlast any oil paint, because most varnishes are not intended for such severe exposure and will not last as long as oil paints, but a varnish paint can be specially made which will outlast any oil paint. There is not time to go into that question tonight, but I am prepared to uphold that statement, as I have made such paints.

The color of paint has something to do with its durability. Pure white lead, or pure white zinc, or any other pure white material, will not last as long as the same thing containing a little tinting material, such as chrome yellow, which is a very enduring color. That is because the coloring matter prevents the chemical rays of light from penetrating the paint, and those chemical rays have a great deal to do with destroying the oil. Although it is understood that white paints are not as enduring as those that are colored, many people want them and always will.

Some three or four years ago Mr. Thompson, chief chemist of our company, was of the opinion that he might get some idea of the value of pigments, with regard to their relation to iron, by suspending them in water. He put a piece of polished or clean steel into a wide-mouthed bottle and filled it nearly full of water and then put in some of the pigment. He had a lot of bottles of different pigments all suspended in the water, and bubbled air through the water to keep it stirred up all the time, and noticed in which bottles the iron rusted the most. He got some incomprehensible results and gave up the experiments. He reported, however, to the American Society for Testing Materials, and they recommended that a committee be appointed to investigate the matter, because it looked so interesting. This was done, and a series of experiments were made. Quite a number of chemists made experiments along similar lines, getting concordant results, and finding that with certain pigments they got much more rusting than with others.

Dr. Cushman, who is chief chemist of the Bureau of Roads, in the Department of Agriculture in Washington, has been employed in this particular matter. One might think that this question is out of his line, but as a matter of fact he investigated to find what is the cause of the rapid destruction of wire fences, which are naturally part of the road work in a good many parts of the country, and that led him to a study of the rusting of iron.

Dr. Cushman classified the various common pigments under three heads: those which stimulated corrosion, those which inhibited corrosion, and those which were neutral. He can tell you exactly which is the worst and which is the best. He says, for instance, that the worst pigment to rust iron is lampblack, and the best is zinc oxide (although I think it is possibly the second best), and so on; he has a list of them. The Atlantic City fence was constructed with the expectation that it would show the value of the stimulators and inhibitors as to paints ground in oil. You understand the tests were all made in water and results are obtained from the water-test in about a week, or in fact can be obtained in a day. I have no such criticism to make of the steel fence that I have of the wooden fence. A lot of fine, big, steel panels,—3 by 2 ft. or something like that, I should judge,—were well painted and put in place. They were all pickeled and cleaned before painting. The committee who went to Atlantic City to look at the wooden fence also looked at the panels in the steel fence. It is known that zinc chromate is an inhibitor, and the zinc chromate panels looked fine. There is a method of preparing Prussian blue, to make it an inhibitor, and that looked fine. With every one of the other inhibitors the paints had failed, while all of the stimulators, without exception, were in fine shape. It was not a surprise to me, though. It is not reasonable to expect that the conclusions that we have arrived at from fifty years' of experience in the use of oil paints are going to be upset by a week's experiments with calcimine. That is about what it amounts to. The experiments with pigments in water have no relation to their behavior in oil. The experiments proved that.

Committee E, of the American Society for Testing Materials, three and a half years ago obtained permission from the Pennsylvania Railroad Co. to paint the bridge across the Susquehanna River at Havre de Grace,—a new bridge. By soliciting subscriptions from paint manufacturers they raised several thousand dollars for the purpose. Nineteen different kinds of paint (and there must have been great differences in the paints) were put on, which were made by the manufacturers who contributed money. The committee hired a master painter,—as good a man as they could find,—and drew up a set of rules for use in painting that bridge. (Those rules make interesting reading.) The painting was to be done in strict accordance with the rules. If the morning was foggy, the painting was discontinued until the fog cleared up; also, no painting was done while it rained; the iron was to be cleaned thoroughly; the paint was to be brushed on thoroughly, covering so many square feet to the gallon, and must be weighed out accurately. There was an inspector to watch the painting, and a man to weigh out the paints, take care of them, and keep them under lock and key. The Pennsylvania Company sent its best inspector there to see how the work was done, and each of the paint manufacturers had a right to have an inspector there. As a matter of fact they averaged to have an inspector there all the time, so there were at least three inspectors and only about three men painting. I can assure you that the committee obtained a splendid piece of work. The committee has been inspecting that bridge every six months. The inspection of less than a month ago revealed the fact that seventeen of those paints look so well that one cannot make any choice between them after three and a half years

That proves one of the things that other paint men as well as myself have been preaching,—that a reasonably good paint, *well applied,* will last a long time. The reason for failure of paints generally is that they are carelessly applied.

Reference was made to Johnson's iron oxide, and it had a pleasing and familiar sound. I introduced myself to the paint business about a quarter of a century ago by going to Three Rivers, Michigan, and opening up the mine where Johnson's iron oxide is made. That is one of my children. I know all about it. I have no doubt one can make an iron-oxide paint that will last a long time if it is well made and well applied, but I will stick to my former assertion that I do not believe iron oxide is the best paint on iron.

In regard to red lead. I have sold paint against red lead for a number of years (although not now), but no one ever heard me say that I did not think red lead was the best first-coat paint to put on iron. Red lead sticks to iron extremely well. There has always been a great difference of opinion in regard to red lead, and I have pointed out in my books and writings on the subject, and talks that I made many years ago, that in all probability that is due to the fact that red lead is so variable a composition. That is my opinion today as well as of other people in the lead business. As I have already stated, we can obtain a red lead containing anywhere from 5% to 45% litharge. It is unreasonable to suppose that all of those materials will be of equal value as paints. We believe that a high percentage of the peroxide of lead makes the best kind of red lead; and I suppose that orange mineral, which is nearly pure peroxide, is the best of the red leads, but it unites with oil in a considerably different proportion and may not be so good on that account. As it also costs a good deal more, very few will use much of it. The price limits its use.

The question was asked whether the setting of red lead and oil is a chemical action. As the red lead containing a large amount of litharge sets with the linseed oil it sets as a cement, and there is undoubtedly a chemical action there. In talking recently with Mr. William Jackson, City Engineer of Boston, about red lead, he told me of having painted a bridge with some practically pure red lead,—that is, peroxide,—which was made for a storage battery quite a number of years ago, and said that the covering lasted indefinitely and was very satisfactory indeed.

The fundamental things are to get the metal clean; paint under favorable conditions; spread on the material at a uniform rate, and brush on well. Elbow grease goes a long way in making the paint durable.

Of course, there is a difference in oil. Linseed oil is the standard vehicle. The present price of linseed oil, about 90c (I do not know of its ever being so high before), is a great temptation to adulterate oil, and it may be that if the price keeps up we shall have to get a substitute for linseed oil. The company with which I am connected make as well as buy linseed oil, so I know something about it. I do not know any substitute for linseed oil that is as good. Of course, we can make varnish that will be better, but the price is too high. We cannot make a varnish suitable for a vehicle for outdoor work that will cost less than something like $2.00 per gallon wholesale. Corn oil is used to some extent to adulterate linseed oil, and it is believed by some that it has merit. Of course there is no reason why oil made from corn should not be just as good as oil made from flaxseed; it is a question of fact; that is all; but it is not naturally a drying oil; it has to be loaded with driers to make it dry, and personally I have a prejudice against it. There is a new oil which has not yet come into extensive use, made from the soja bean, which is imported from Manchuria. The soja bean is raised in the southern states for fodder and will grow in diverse climates. From what I have heard about it from some of the paint men, I am led to believe it is a fairly good oil. It is sold at the present time at about 51c, so there is naturally a temptation to experiment with it. Up to the present time I do not know that there are any vehicles that are equal to linseed oil. Perfectly honest linseed oil is not all alike, because the seed is not all alike. It may be made in the same way but the seed varies in purity as well as quality. It may get a little moldy in the shock or bundle when it is being harvested, and such seed may produce an oil which has more or less free fatty acids in it. There is no question but there is a difference in commercially pure linseed oil made from flaxseed by people who intend to make good oil.

Some of the graphite paints are undoubtedly good paints, while some of them are extremely poor. Some of the alleged graphite paints do not contain any graphite whatever; the pigment is nothing but some coal-shale that has just enough carbon in it to make it black. The same can be said of those iron oxides. Some of them contain 95% iron oxide, some not more than 15% or 20%, and some still less than that. There is no regularity about them.

The kind of drier that is used also makes a great difference in the durability of paints. I can make a drier that will kill any paint, easily, too. With a good drier, a good oil with any decent kind of pigment, a very good paint can be made.

ELECTROSTATICS AND ELECTRIC IMPULSE FORCES.

CHARLES P. STEINMETZ.

The subject of tonight's discussion, Electrostatics and Electric Impulse Forces, has with the development of the industry in the last years become extremely important. It is not new, however. Investigation of these subjects dates back to the earliest days of electrical science, long before there was any electrical engineering. Indeed, the earliest investigations of electricity were made in electrostatics, on static machines,—that is, machines which gave a high voltage but only a negligible or extremely small current. These were investigated, and soon afterwards came in also the so-called *galvanism,* a study of electric currents of moderate amperage and extremely low voltage, battery currents. This was before the time of electrical engineering, and it has always appeared to me rather a remarkable indication of the clear insight of these earlier investigators that they realized the identity of these two sets of phenomena,—those of electrostatic machines, where we deal only with electrostatic fields, practically no magnetic effects, and those of the galvanic currents, where we have no appreciable electrostatic effects but only the magnetic effect of the current.

When electrical engineering started, the electrical engineers got very little, if any, benefit from these early investigations. As frequently happens, scientific work had been done on quantitative relations outside of those which were important to the engineer. When designing the first electric distribution for lighting and power, at 110 volts and 220 volts, the voltage was so very much lower than the voltage which the old electrostatic machines gave that experience with the one did not apply to the other. For instance, many materials appeared as conductors for the small quantity and high voltage of a static machine, wood and strings and so forth, but were nonconductors for the 110 volt lighting current. With the static machine all metals were perfect conductors. There was no difference appreciable. But with the lighting current there were very great differences in the conductivity of different metals. The experience with galvanic currents of a few volts was also inapplicable. There practically everything was insulating except metal. Not so with the lighting circuit. When the earlier pioneers tried to lay their conductors in the ground they soon found that this did not go; there was too much leakage, it short-circuited the circuit. So you see the electrical engineer had to start anew and develop a knowledge of the phenomena of electric power from an engineering point of view.

Those electrostatic phenomena of the early investigators remained still—for a long time at least—in the text-books and the instruction of our colleges, and at least the older ones of us will recall that our knowledge of electricity started with mathematical, theoretical investigation of electrostatic phenomena, beginning with a triple space integral, which ultimately reduced to a double surface integral and then still farther reduced until we came to isolated points and led to the conclusion that all action of forces issued from the sources of the forces, which physically is obvious. Then we had the study of the distribution of electric charge, whatever that may be, on an ellipsoid, as this happened to be about the only body where the mathematical problem may be solved without too formidable difficulties, although I have never seen any electrical engineering in which an ellipsoid of any use appeared.

And then we came to the interesting conclusions that electricity—that is, the electric charge—exists only on the surface of the conductors;—there is no electricity, no electric charge, no electric field inside of the conductor. Now the first thing that was done in electrical engineering was to show that the electric current passes through the entire cross-section of the conductor, not on the surface alone. So you see there was a big discrepancy between engineering experience and the theoretical conclusions of electrostatics, or at least an apparent discrepancy;— in the one, electricity exists only on the surface of the conductor; in electrical engineering electricity flows through the entire section of the conductor.

Now young engineers usually do not start any more with electrostatics and the mathematical theory of the electrical field, but immediately begin with electro-dynamics, with electrical engineering.

In those years of the gradual development of electrical engineering, we have progressed to higher and higher voltages. We have arrived at 20,000 volts underground cables, at transmission lines passing beyond 100,000 volts, and there are now in successful operation in this country quite a number of long-distance transmission lines operating at voltages above 100,000. These voltages are higher than the voltages given by most electrostatic machines, higher than the voltages on which the early work on electrostatics was done, and no electrostatic machine was ever built reaching as high voltages as are in every day use in testing transformers, 300,000 and 400,000 volts. So you see the electrical industry has reached up to voltages beyond those with which the early work was done; and not voltages of insignificant power, where there is no current flowing, but voltages with very considerable power back of them. This makes it necessary now and essential for us, as engineers, to study and become familiar with the phenomena of electrostatics, because we meet them in our every-day circuits, our 20,000 volt underground cables and our 60,000 to 100,000 volt transmission lines.

The first difficulty we find in dealing with the electrostatic field is the great inconvenience, or lack of ability, to get a physical conception. The whole field of electrostatics is very difficult to approach and to get such a clear insight into it that we really know what is going on. It is easy enough, or, rather, it is possible, mathematically. to state many things; but to an engineer a mathematical investigation, or a mathematical conclusion, is of no value whatever if he cannot get a clear insight, a physical picture, of what goes on. The mathematical discussion may be all right for scientific investigation, but an engineer must see what it means lest he be led astray and draw some conclusions or get some results which do not agree with the apparatus built, or which resulted in the apparatus not operating in correspondence with his conclusions. So you see the first requirement that we need is a clear physical picture, a conception of the electrostatic phenomena.

In the magnetic field this engineering conception of the phenomena has been given to us by Faraday, who probably was the greatest electrical engineer we had. I do not think he ever did any engineering work, but his mental attitude, his way of looking at things, was that of the successful engineer, not of the mere scientist. He was not satisfied to get the theoretical formalism, but he wanted to see the thing, to see what was going on, get a physical conception, a picture, and that is what the engineers have to do to handle the phenomena successfully. In the magnetic field, Faraday has given us the conception of the lines of magnetic force, and, as you know. we are able with very little difficulty to discuss and understand and calculate with any desired degree of accuracy the most complicated and complex magnetic fields. It is hard to conceive of a more complicated magnetic structure than, for instance, the magnetic field of an electric generator. You have there a magnetic circuit of heterogeneous materials,—cast iron and steel and laminated steel,—of very irregular shape, in series with an air gap, on one side of the gap, polar projections, interpolar spaces, and the other side cut up by teeth and slots, etc ; in short, it is such a complicated structure that it would be utterly impossible to calculate its magnetic circuit strictly mathematically, if we did not have this clear conception of the lines of magnetic force whereby we can see how the magnetic flux is passing, and we therefore are able to calculate it by approximation. We know the flux passes in the iron. We know it strays across the slots and interpolar spaces. We can easily see approximately how much to allow or what approximation we can make. That gives us confidence that while we may get an approximate result only, it will not be far off. Only imagine if we could not see what is going on there, how it is the magnetic flux passes, if we would take a set of mathematical formulas and calculate from them to get a result. You see we then cannot approximate because we do not know without any physical picture what the approximation means, whether far off or near the actual results. All engineering calculations lead to a complicated structure: theoretically we can, but practically we cannot, tell by calculation with absolute exactness, because life is too short for that; we have to approximate. But when we approximate a thing, if we do not see the physical characteristics of it in every detail we cannot judge of the relative magnitude. That, no mathematical equation can give you. You see, as a result, the magnetic field is in our reach. We do not think it is anything formidable, difficult to understand or weigh; but as soon as we come to the electrostatic field our trouble begins; we have electrostatic charges on the conductor. we have the surface density of electricity, and all kinds of such weird phenomena. We had the same, before Faraday, in the magnetic field. We then spoke of charging a steel bar with magnetism, spoke of the quantity of magnetism or magnetic strength, considered it as distributed over the ends of the steel bar; the distribution being such that it can be represented by two poles having about five-sixths of the length of the steel bar as distance from each other. We then went still farther and said that north magnetism and south magnetism are magnetic charges on the steel bar, but they are really not one at one end and the other at the other end, because if we break the magnet in two each part is a complete magnet. So we had to assume each molecule magnetically charged with north and south magnetism. Now these conceptions of magnetic charges, magnetic quantities, pole strength, etc., have disappeared. We speak of magnetic flux, which we measure by lines of magnetic force; the number of lines of magnetic force, or density of the magnetic force in lines of force per square centimeter or square inch; the magnetomotive force and magnetizing force which produce this magnetic flux;—all conceptions which are physically before our eyes and of which we can make a picture.

In electrostatics the field has been left as it was in the days before Faraday. The same conception is there, of an electrostatic charge and the electrostatic quantity, and we have the same difficulty if we desire to approach electrostatic phenomena as we had with magnetic phenomena before Faraday. Therefore, if we desire to understand the electrostatic field, to handle it intelligently,—and we have to do that because in the electrical industry it has become now of engineering importance,—it means we have to get just as clear a physical picture of the electrostatic field as we have of the magnetic field.

The conception of Faraday of the lines of force applies to one just as to the other. Just as we represent the magnetic field by a magnetic flux measured by the number of lines of force, so in the electrostatic field we can conceive an electrostatic flux measured by the number of lines of electrostatic force. This gives the same picture, the same physical conception, and the same accuracy of dealing with it. and we may make calculations with as high accuracy as our time allows, or may approximate it and still with every approximation have a clear insight as to how far off the approximation is. which we make.

Now let us look into what is going on in an electric circuit.

Suppose we have an electric generator supplying power over an electric circuit into some receiving circuit. We have, then, a source of electric power, a consuming circuit and a transmission circuit connecting the two. Let us first see what goes on in this transmission circuit. We have electric power flowing through it. As a result, therefore, we have a consumption of electric power in the conductor by conversion into heat. But that is not all. We also have something taking place outside of the conductor. If we take a small iron needle suspended movably and bring it near the conductor while electric power flows through the circuit, we find there is a force acting upon the iron needle. It moves and it puts itself in a direction concentric with the conductor, as shown in Fig. 1, where the central black circle denotes the conductor section, the arrows the position of the iron needle. The iron needle is acted upon by a magnetic field and puts itself in the direction of the magnetic field, that is, in the direction of the lines of magnetic force. So we find, then, that when electric power flows through the circuit, there is a magnetic field surrounding the conductor and that magnetic field consists of lines of magnetic force which surround the conductor in concentric circles, as shown in Fig. 1.

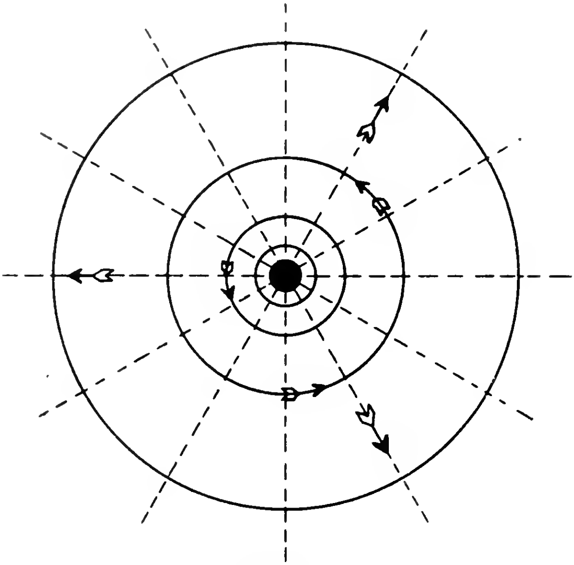

Fig. 1.

Suppose we take a needle-shaped movable body, conducting or semi-conducting, and bring it near the conductor. For instance, we take a piece of string and tie it to the conductor. While electric power flows through the conductor, that string or whatever it may be will move and will put itself in a direction radial to the conductor. Now a light moving body is acted upon by an electrostatic field and the needle shape or string thus puts itself in the direction of the lines of electrostatic force. If you sit on a chair on a static machine your hair stands up: you put yourself in the direction of the lines of electrostatic force. So a string on a conductor, if the voltage is high enough, points radially outward, showing that there is an electrostatic field surrounding the conductor and the lines of electrostatic force are radially issuing from the conductor, as shown in dotted lines in Fig. 1.

Now, let us go a little farther. Consider not only one conductor but the conductor and the return conductor, as shown in Fig. 2. The result is that the lines of magnetic force are crowded together more between the conductors; instead of concentric circles they become eccentric circles, being nearer together in the middle. The lines of electrostatic force also are crowded together more between the conductors; instead of radii they become arcs of circles, as shown dotted in Fig. 2, passing from conductor to conductor. In either case, however, we find outside of the conductor an electrostatic field and a magnetic field, as we can show by those phenomena, which are manifestations of the two fields respectively.

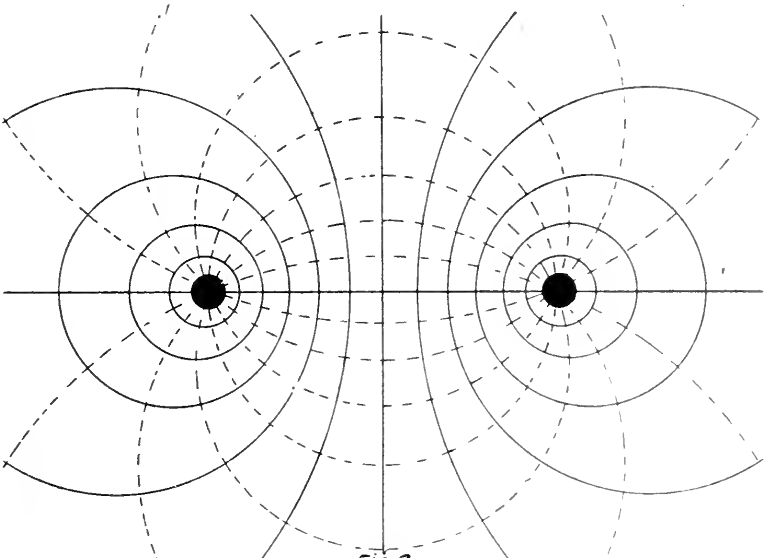

Fig 2

What relation have these fields to the flow of power through the conductor? We find neither of the two—neither the magnetic nor the static field—is proportional to the flow of power. We may with the same magnetic field have a large amount of power or a small amount of power pass through the same conductor, depending on the voltage. We may with the same static field have a small power or a large power, depending on the current. You see the two fields are not proportionate to the flow of power, but the magnetic field—that is, the total number of lines of magnetic force surrounding the conductor—is proportional to the current in the conductor. The proportionality factor of the magnetic field Φ, with the current i, is called *inductance,* and is denoted by L. That is, it is: $\Phi = L\,i$. The proportionality factor of the electrostatic field ψ, with the voltage e, is called the *capacity* of the circuit, and is denoted by C. That is:

$$\Psi = C\,e$$

You see here the meaning of inductance and capacity as two constants of an electric circuit. We have the magnetic field surrounding the conductor and the electrostatic field surrounding the conductor, through which electric power flows, and corresponding thereto the three constants which every electric circuit has—R, L and C. R is the resistance representing the power consumption in the conductor; L the inductance, the proportionality factor of the magnetic field of the conductor; C the capacity, the proportionality factor of the electrostatic field of the conductor.

I have spoken here of the magnetic field as $\Phi = L\,i$. That means I count every line of force which happens to go around the circuit twice or several times, as many times as it surrounds the circuit. This we do not need to consider here, where for simplicity I consider only a straight conductor, as a transmission line. The phenomenon remains the same when dealing with coiled circuits, and so forth, only there each line of magnetic force is counted as many times as it goes around the circuit.

The magnetic field can exert force and thereby do work; hence it contains energy. The magnetic field must thus represent a certain amount of energy. The same applies to the static or dielectric field; since it can do work it must contain energy. And so we see the two component fields, the magnetic field and the dielectric field, represent stored energy. This being the case, let us consider the magnetic field first. As it represents stored energy, to produce it energy must be supplied to it, from the electric circuit. That means power must be consumed in the electric circuit in supplying the energy of the magnetic field. Now electric power is e times i. The magnetic field being proportional to the current i, it means that in producing it, in consuming power, a voltage must be consumed, a voltage e, which with the current i gives the power p which supplies the energy of the magnetic field. Since it requires energy to produce the magnetic field, but does not require energy to maintain it, the voltage e', which with the current i supplies this energy, must be proportional to the increase of the magnetic field. That is:

$$e' = \frac{d\,\Phi}{d\,t}$$

and since $\Phi = L\,i$, this gives:

$$e' = L\frac{d\,i}{d\,t}$$

and the power consumed in producing the magnetic field thus is:

$$p = i\,e' = Li\frac{d\,i}{d\,t}$$

hence, the energy of the magnetic field:

$$w = \int p\;d\,t = \int Li\;di = \frac{L\,i^2}{2}$$

So you see the stored energy of the magnetic field is $\frac{Li^2}{2}$, and this is supplied by power from the electric circuit—that is, as current i, which is proportional to the magnetic field, times a voltage e, which is induced in producing the magnetic field. When the magnetic field disappears this voltage is negative, the power is negative, that is, the energy is returned.

Let us look at the same conditions in the electrostatic field. The electrostatic field also represents stored energy which is to be supplied by power, from the electric circuit. The electrostatic field is proportional to the voltage:

$$\Psi = C\,e$$

therefore must consume current in being produced, and that current must be proportional to the rise of the electrostatic field, that is, must be:

$$i' = \frac{d\,\Psi}{d\,t}$$

and since $\Psi = C\,e$,
it is:

$$i' = C\frac{d\,e}{d\,t}$$

and the power consumed in producing the electrostatic field thus is:

$$p = e\,i' = C\,e\frac{d\,e}{d\,t}$$

hence, the energy of the electrostatic field:

$$w = \int p\ dt = \int C\ e\ d\ e = \frac{Ce^2}{2}$$

You see you have identically the same in the static field as in the magnetic field. Both represent energy; both, therefore, have to have power supplied from the electric circuit, which power is returned at the disappearance of the field. The one, which is proportional to the current, therefore consumes a voltage in appearing. The other, which is proportional to the voltage, therefore consumes a current in appearing and receiving energy. Thus, analogous to the voltage e' consumed by the production of the magnetic field, we have the current i' consumed by the production of the static field of the circuit. The former e', is called the *inductance voltage,* or *e. m. f. of self-induction;* the latter, i' the *capacity current,* or *charging current.* Thus the capacity current is analogous, in the static field, to the inductance voltage in the magnetic field.

Now see what we do if we do not have a proper conception of the static field. That capacity current we call *charging current* and imagine an electrostatic charge, as some quantity of electricity which flows on to the conductor and remains there. Ages ago we dropped the corresponding conception in the magnetic field; we do not speak of the inductance as the charging voltage, which puts a magnetic charge flowing on to the conductor and remaining there to return with the decrease of current. Try this conception on the magnetic field and see how helpless you would be in dealing with and calculating magnetic fields. In the electrostatic field this ancient conception of a charge has still largely survived and accounts for most of the difficulties in dealing with static fields. There is no such thing as an electric charge on the conductor, no more than there is a magnetic charge on it. The capacity current is giving the energy of the static field just as the inductance voltage is giving the energy of the magnetic field. This conception of Faraday's lines of force enables us to deal with the electrostatic field just as simply and intelligently as we are used to deal with the magnetic field. We measure the magnetic field by the number of lines of magnetic force ϕ; so we measure the electrostatic field by the number of lines of electrostatic force ψ. Just as we speak of a *magnetic flux* ϕ, so we should properly speak of an *electrostatic flux*, or *dielectric flux* Ψ.

The magnetic flux per unit area, as per square centimeter, is the magnetic density:

$$B = \frac{\phi}{A}$$

In the same manner we can consider the electrostatic flux per unit area, the number of lines of electrostatic force per square centimeter, the *electrostatic density, or dielectric density:*

$$D = \frac{\psi}{A}$$

B equals μH, where μ is the permeability, and *H* the field intensity; that is, the magnetic density or number of lines of force per square centimeter which would exist in the air, or rather in empty space. So, also, *D*, the electrostatic flux density, equals κ, *K* where *K* is the electrostatic force or number of dielectric lines which exist in air, or rather in empty space, that is, the *dielectric intensity*. κ then is the constant corresponding to permeability. That is, it is the specific capacity or, a name suggested by Heavyside, the *permittivity* of the electric field. Permittivity and permeability both are constants of the material in which the electrostatic or electromagnetic field exists and both relate the flux density in empty space to the flux density in that material which we are considering.

So we have in the electrostatic or dielectric field the analogous relations as in the magnetic field.

μ, the permeability, is unity or very near unity for most materials, with the exception of a certain number, more than is usually assumed but still a limited number, in which the permeability is very much greater than *1* and may reach beyond 1000, the so-called magnetic materials.

κ, the static conductivity or permittivity, or, as usually called, the *specific capacity*, is very close to unity with all gases, but with solids and liquids is usually higher. Most of the materials are in a very narrow range, between 2 and 6, rarely going below 2, rarely going above 5, though there are some as high as 10 or 12; and some semi-conductors, like water, have even very much higher values, though it is questionable then whether we are dealing with the same constant. However, the difference is merely a question of numerical values, but these two constants, μ and κ, are entirely analogous, one in the magnetic field and the other in the static field. The magnetic and the dielectric quantities discussed in the preceding are collected in the following table:

ELECTRIC FIELD.

Magnetic Field:	Electrostatic Field:
Magnetic Flux:	Dielectric Flux:
$\Phi = L\,i \quad (10^{-8})$	$\Psi = C\,e$
Inductance Voltage:	Capacity Current:
$e' = \frac{d\Phi}{dt} \quad (10^{-8})$	$i' = \frac{d\Psi}{dt}$
$= L\frac{di}{dt}$	$= C\frac{de}{dt}$

Power: $p = i e'$ $= L i \dfrac{di}{dt}$	Power: $p = e i'$ $= C e \dfrac{de}{dt}$
Magnetic Energy: $w = \int p \, dt = \int L i \, di$ $= \dfrac{L i^2}{2}$	Dielectric Energy: $w = \int p \, dt = \int C e \, de$ $= \dfrac{C e^2}{2}$
Magnetic Density: $B = \dfrac{\Phi}{A}$	Dielectric Density: $D = \dfrac{\Psi}{A}$
M. M. F.: $F = n i$	E. M. F.: e
Magnetizing Force: $f = \dfrac{F}{l} = \dfrac{ni}{l}$	Potential Gradient: $g = \dfrac{e}{l}$
Magnetic Field Intensity: $H = 4 \pi f \, 10^{-1}$	Dielectric Field Intensity: $K = \dfrac{10^9}{4 \pi v^2} g$
Permeability: μ ($= 1$ for vacuum)	Permittivity (Specific Capacity): κ ($= 1$ for vacuum in electrostatic units)
Magnetic Density: $B = \mu H$	Dielectric Density: $D = \kappa K$

l = length, A = section of magnetic resp. dielectric circuit, v = velocity of light, $= 3 \times 10^{10}$ cm. sec.)

Let us investigate now what happens if we study the magnetic and electrostatic flux density, the number of lines of force per square centimeter or square inch, B and D. By increasing H and K, that is, the magnetic respectively dielectric intensity, we increase the densities B and D. With those materials which show a high permeability, the magnetic materials, we find B does not increase proportionally but the increase gets less and ultimately practically stops; that is, we reach a saturation value of magnetic flux density, which with iron is about 20,000 lines per square centimeter, or 130,000 lines per square inch. That saturation value means so large a flux density passes through the iron, and as soon as that is reached any further increase of flux density is merely the increase of H, that is, from that density upwards the slope of the B in iron is the same as it would be in air. So we find in magnetic materials a saturation limit.

Similar phenomena we find in the electrostatic field. If we gradually increase the potential gradient g or the voltage per centimeter, that is, the dielectric intensity K, we find the electrostatic flux, the number of lines of dielectric force per square centimeter, D, increases further and further up to a certain saturation value where no further increase takes place. Then the material becomes conducting, and when it becomes conducting it means that there is no appreciable potential difference, no appreciable voltage gradient across it, and current passes. We say then the insulating material breaks down. We see the phenomenon of dielectric break-down is analogous, to some extent, to the phenomenon of magnetic saturation: A finite value of electrostatic flux is reached at which the material cannot carry any more electrostatic flux, but ceases to be a carrier of electrostatic flux and becomes a conductor. There is a critical saturation value of the electrostatic field, or a critical potential gradient which corresponds to the maximum possible flux density. In air it is about 35,000 volts per centimeter. This value is called the *dielectric strength*, or *disruptive strength* of the material, and corresponds to the *saturation value* in the magnetic field. If the material is a solid it is destroyed, when passing dielectric saturation or disruptive strength; if it is a gas it becomes luminous, gives a *corona*. Just as the flux distribution in the magnetic field changes when a part of the iron becomes saturated, so the dielectric flux distribution changes in the static field when any part is saturated, becomes conducting. That means the distribution of voltage also changes, and where formerly there was a high potential gradient there is now no voltage, but conductivity.

For instance, let us consider a very simple electrostatic field: that between two parallel cylinders, as the two conductors of a long-distance transmission line, as shown in section in Fig. 2, in a medium of specific capacity or permittivity 1, that is, in air. Such a magnetic field would be one of the simplest imaginable and could be calculated without any difficulty. In the electrostatic field there is no greater difficulty than in the magnetic field, in calculating it in the same manner, by the conception of the lines of dielectric force. The dielectric density naturally is the maximum at the conductor, and with increasing voltage, we reach ultimately at the conductor the saturation value of the dielectric density, and with still further increase of voltage this saturation value passes farther and farther outwards from the conductor, and we get a range, a volume of air around the conductor, where the static field has passed its saturation value, and where the space, the air, has become conducting and luminous, which we call the corona. The corona which forms at high voltages upon conductors is nothing but the result of the electrostatic field density passing beyond the saturation value, so that the electrostatic field becomes conducting, the gas becomes luminous or the corona forms.

The configuration which the electrostatic field then assumes is given by the same class of calculation as with corresponding magnetic fields: it is the dielectric field of two conductors having the section of the space filled by the corona.

Going a step further:—we know when we produce an electrostatic field we store energy in the medium. This energy is returned, when the electrostatic field decreases again, the same as in the magnetic field. The magnetic field when rising consumes energy by the inductance voltage and the current being in the same direction; it returns this energy when decreasing, by the inductance voltage and the current being in opposite directions. Thus energy is consumed by the capacity current of the rising dielectric field being in the same direction as the voltage, and is returned at the decrease of. the dielectric field by the capacity current and the voltage being in opposite directions. We possibly do not return quite the same amount of energy as we consumed because of the hysteresis loss, which is very marked in the magnetic field, especially when there is iron or other magnetic material. It is usually very small in most static fields, but not necessarily so.

Now let us see what happens when the electrostatic field goes beyond the saturation value. With increasing voltage, and thus increasing dielectric flux, energy is stored in the space here until the saturation value is reached, and the static field becomes a conductor. At that point, then, where the space becomes conducting the energy discharges as current, is converted into heat, and thus not returned at the decrease of the dielectric field. As far as the static break-down extends, that is, as far as the saturation value is exceeded,—which is merely a calculation of electrostatic fields,—the corona spreads, and the energy stored in this space by the saturation value of the dielectric field is not returned but is dissipated as corona loss. This allows the calculation of the loss of power by the corona.

We know the potential gradient at saturation,—about 35,000 volts per centimeter. This gives us the stored static energy per c.c.m. and for every half wave of voltage. Multiplied with twice the frequency, it gives the power loss per c.c.m., and multiplied with the volume filled by the corona—as calculated from the static field—it gives the total power loss in the corona. Of course, we will have to put all these quantities into the same system of units, into magnetic units, to get the numerical values. I cannot do this here, but what I wanted to show is that theoretically there is no serious difficulty if we apply to the dielectric field the same conception which Faraday applied to the magnetic field, in calculating all those more or less mysterious phenomena of the appearance of corona, the power loss in the corona, and so forth. It is no more difficult than magnetic calculations. Naturally we must know the constants of the materials, just as in the magnetic field we have to determine the constants, the permeability and the magnetic saturation. So we have to get the specific capacity or permittivity, and the saturation value or dielectric strength of air and other materials. I gave 35,000 volts per centimeter, but that is only an approximation. We do not yet know the values very accurately, and just as in magnetic circuits when we come to the calculation of numerical values we have to consider secondary phenomena, as stray fields, and so forth, so it is quite likely that secondary effects will come into consideration also in the dielectric field.

The main feature which I wanted to point out is that the static field is inherently no more difficult but rather simpler in treatment than the magnetic field.

It is interesting to see why these phenomena, as corona, for instance, have become of importance in the last years. Energy loss begins as soon as the saturation value of the static field is exceeded at the conductor. The voltage at which the saturation value at the conductors is exceeded and the corona begins, depends on the size and the distance of the conductors. The smallest size of conductor that we could consider for a high voltage circuit is probably ⅛ in., and this is rather exceptional. Usually we have much larger conductors for mechanical strength. With conductors of ⅛ in. the saturation value of the static field is reached at the conductor surface, depending on their distance apart, somewhere between 50,000 and 80,000 volts between the conductors. When we use such voltages in commercial circuits we have to get a considerable distance between the conductors; that is, the value of voltage at which we would expect corona to begin probably is near the upper limit, 70,000 to 80,000. So, when we were limited to 60,000 volt circuits we did not yet get into the range of voltages where corona might form on the conductors, even with the smallest size of conductor which we could use, but when we came to 100,000 volts and over, then we found that we had passed the voltage range where corona begins even a considerable distance between small sized conductors. We are now just entering industrially that range of voltages where the phenomenon becomes appreciable, and in those 100,000 volt lines we are beginning to get a saturation of our static field at the conductor and corona formation near the conductor. We have not observed it before. Naturally, if we bring the conductors closer together the voltage at which corona forms, at which we reach the breakdown value, is much lower. It may go down to 20,000 or 30,000 volts. If we put a dielectric or high insulating value and fairly high specific capacity on the conductors, and bring them still nearer together, with a dielectric of lower capacity, as air in the insulating material or between the insulating material, we may reach the breakdown gradient at even lower voltages. At 5,000 to 10,000 volts occasionally we may see corona in such cases.

Some further conclusions we can draw from the consideration of these phenomena. We have seen that energy is stored in the electrostatic field and in the electromagnetic field. Every electric circuit has inductance and capacity,—that is, has energy stored in a static and magnetic field,—the one depending on the current, the other on the voltage. We cannot make any change in the circuit, cannot change the voltage, cannot change the current, without a change of either the one or the other field or both, that is, without a change of stored energy. Any change of stored energy means that power must be supplied to or returned from the field. So whenever any change is made in a circuit—an increase of load, decrease of load, change of voltage or current—it must be followed by a readjustment of the stored energy of the two fields. That is, before the conditions can become permanent there must be an intermediate period when energy is supplied or returned from the electric field of the conductor. If we open the circuit, it means the current must cease to flow, its magnetic field must cease as it is proportional to the current. The magnetic energy cannot be dissipated instantly because the only source of dissipation is the resistance, and this, with a limited current dissipates energy only at a limited rate. The magnetic energy must return to the generator, which it cannot do if disconnected, or turn into a receiving circuit, which may be possible or not: if the receiving circuit, for instance, is a transformer with the secondary circuit open, and incapable of dissipating appreciable energy, the magnetic energy must be converted into some other form of energy, that is, into static energy. It means the $\frac{Li^2}{2}$ of the magnetic field converts into static energy, into $\frac{Ce^2}{2}$. Hence, if we know the inductance L of the circuit and the capacity C, from the current i, which we interrupt, we get the voltage e by the equation:

$$\frac{e^2C}{2} = \frac{i^2L}{2}$$

The stoppage of the current thus results in a conversion of the magnetic into static energy, and thereby the production of an over voltage. Inversely, if we have an electrically charged transmission line, and discharge it, we get a discharge current by which the static field of the voltage, $\frac{Ce^2}{2}$, is converted into a magnetic field, $\frac{Li^2}{2}$ of the discharge current.

Assume now that the current flow is stopped suddenly. Its energy changes to electrostatic energy and we get a voltage on the conductor,—a high positive voltage at one end, a high negative voltage at the other end, neutral in the middle,—at the moment when the current has come to a stop. Such voltage distribution cannot continue, but has to equalize by current flowing in the opposite direction; when the voltage is equalized the current flows again in the conductor, but as it cannot continue to flow, its magnetic field converting into static energy now produces again a high voltage, positive at one end, and negative at the other end. So we get a succession or series of conversions of static into magnetic and magnetic into static energy; that is, we get oscillations of current and voltage, of which the one can be calculated from the other. They gradually decrease in intensity, by the dissipation of the energy in the resistance, etc.

That is one case,—an oscillation of the electric circuit, a stationary or standing wave. Now we may take another case. Suppose at one point of the circuit we get a high voltage, say by lightning striking the line and locally putting on a high static charge, a high energy $\frac{Ce^2}{2}$ of the static field; or, inversely, it may be a high negative value, for instance, by a spark discharge from the conductor to ground: the conductor had a high voltage against ground. If then locally its voltage is dropped down to zero, it gives the same effect as if we had in addition to the normal voltage put on a high negative voltage, and this local discharge of the conductor has the same effect, only with the direction of the voltage reversed, as a local high overcharge.

Such a local disturbance of the circuit then travels along the circuit, as successive waves of voltage and current, by which the energy of the local disturbance is transmitted along the circuit and thereby equalized in a similar manner to waves in water, caused by dropping a stone in it, which travel over its surface in dissipating the energy, equalizing the local disturbance. That is a different class of phenomena from the one we discussed before. The former was a stationary wave—an oscillation—in which energy does not flow along the circuit, but by a series of oscillations the energy adjusts itself to the changed conditions of the circuit. In the latter—the impulse or traveling wave—the energy progresses along the circuit. We still have electromagnetic and static energy, but they follow each other along the circuit. If we consider any point of the circuit, over which the wave passes, we get alternately magnetic energy of current, and static energy of voltage. Since it is the same energy going from one to the other form, we must have the same relation

$$\frac{Li^2}{2} = \frac{Ce^2}{2}$$

That is, the traveling waves of current and voltage are related to each other by the above equation.

Let us take some practical case; for instance, an underground cable. In the underground cable the capacity C is very high; the inductance L is very low. That means, their energies being equal in the traveling wave, i must be large, and e must be low in the impulse or traveling wave of a cable. We get large oscillating currents at moderate voltage.

Let us take the reverse case; a circuit having very low capacity but very high inductance, as the high potential winding of a step-up transformer. There L is high, and C is low. If we get an impulse passing through the transformer, i will be low and e high. So we see an impulse in a circuit of low inductance and high capacity is accompanied by large currents but moderate voltage, while in a circuit of low capacity and high inductance we get high voltages and low currents.

Now let us see what happens if such an impulse or traveling wave passes from one class of circuit to another, as is continuously the case in our industrial circuits, at the connecting points of cables with transformers or generators. An impulse coming at high current and low voltage from a circuit of low inductance and high capacity now meets a circuit of very low inductance, but when the wave travels from the cable into, say, the transformer coil, its energy must remain the same. the $\frac{Li^2}{2} = \frac{Ce^2}{2}$ must remain the same before and after, but if the L in the reactance or transformer is a hundred times higher, and the C a hundred times lower, it means the i^2 must be a hundred times lower and the e^2 a hundred times higher; that is, i is decreased and e increased ten fold in the transition from cable to transformer.

Thus, when a wave passes from a circuit of low inductance and high capacity into a circuit of high inductance and low capacity, the current decreases and the voltage increases at the same rate, with the $\sqrt{\frac{L}{C}}$. That is, a transformation of current and voltage occurs at the transition point between two classes of circuits and the nature of the transformation we see from the above equation. It means, when we get to higher reactance and lower capacity we get a transformation of the current downward and of the voltage upward, and an impulse, which in the cable may be entirely harmless in voltage, though of considerable current, where it enters an inductive circuit, as a transformer, changes to a high voltage and thereby may reach a destructive value. In the above consideration, in going from one to the other circuit we assume that the LC, inductance times capacity per unit length, in both circuits is the same. Take a cable and a transformer. What should we use as unit lengths? There is no particular reason why we should use the same linear measure in the coiled conductor of the transformer as in the underground cable. So we take such a unit length that the LC in both circuits is the same. $\sqrt{LC}$ is inverse proportional to the velocity of propagation. Hence, hereby we choose as unit length in both types of conductor the velocity, that is, the distance traveled by the impulse at the same time. As the result, you get the same energy per unit length.

So we see at any transition point between two electric circuits we get a change of current and a reciprocal change of voltage, a transformation of the electric wave or electric impulse into increased current and decreased voltage, or decreased current and increased voltage, depending upon the relative inductance and capacity of the circuits. In a circuit of low inductance and high capacity we get high current and low voltage. In a circuit of high inductance and low capacity we get low current and high voltage. It means, then, when we interpose a circuit of high inductance to the impulse to cut the current down, at the same time we increase the voltage and that inductance must be insulated for very high voltage, otherwise it will jump across. We get an obstruction of the current impulse by building up its voltage, and while the voltage may be harmless farther out in the cable, it may become destructive at the entrance to the apparatus. We find not infrequently that sparks will jump across terminals, which indicates a voltage very much higher than the apparatus would stand in its interior, very much higher than the cable a few feet away would stand without puncture. It is merely the effect of a transition point where the current builds down and the voltage builds up and jumps across.

These impulses, though, differ somewhat from the phenomena we are familiar with in the steady voltages. Steady voltages we know to have unlimited power behind them. Here we see we have a certain static energy, or magnetic energy, that may be fairly large if it is energy of a long distance transmission line, but still, even then, it is very small compared to the energy which the generating system could give in a few seconds. If it is a traveling wave or impulse originating in a short length of circuit, its energy is extremely small, but where it transforms there is no limit to the voltage, it depends entirely upon the inductance and capacity ratio of the two circuits. In electric impulses we may get indefinite and practically unlimited voltages, but of limited energy. They have to be dealt with in a very different manner from the limited steady voltages of unlimited power. We must find means to dissipate their energy by having it discharge harmlessly into space as corona or through high resistances.

Now the question is, how frequent are those impulses? They are rare in small, low voltage circuits. When we come to these very big, high voltage circuits, however, like a 20,000 volt underground cable circuit, then we find impulses traveling over the system practically continuously. I do not believe that there is any moment of time when there are not some high frequency waves running along. We get a similar condition in the ocean. In the ocean, a very large body of water, there are always waves on the quietest day, without any apparent cause. We do not find those in a small pond or a pail of water. If there is a storm, or a heavy wind, we get very big, disastrous waves in the ocean, but it is never free of waves, free of impulses. The same is true in the big underground cable systems, in the long distance transmission lines. Impulses or traveling waves we always have, and we always have to take care of them. There is, however, one difference between the long distance transmission line and the high voltage cable system, and that is the relative resistance. The resistance of the conductor relative to inductance and capacity is very much larger in transmission lines than in the underground cable system. That means that the damping effect on the wave is very rapid in the former, and we may have such an impulse that we have within 50 ft. of conductor a potential difference of 20,000 volts and a mile away from this point there is practically nothing. That is, the overhead long distance transmission line corresponds to an ocean of oil or molasses, a fluid of high internal friction where there are always waves, but they do not pass to any distance, they are damped down very rapidly, while the underground cable system with its relatively high resistance represents our present ocean, which is never free from waves and where the waves roll for any distance, practically over the whole ocean. Wherever they strike an obstruction, a reactance, a transition point to a circuit of higher inductance, they are transformed up in voltage, down in current, just as the ocean wave when it meets an obstruction piles up in height. So we get very analogous phenomena.

What I mainly desire to draw attention to is the simplicity of the electrostatic field and the phenomena related to it, if we consider it in the same way as the magnetic field, by Faraday's conception of the lines of force.

THE RELATION BETWEEN BANKER AND ENGINEER.*

J. C. KELSEY.

Presented April 10, 1908.

In all public-utility financing will be found the bankers. They are as necessary as doctors and nurses in a plague. They furnish the respectability and responsibility, and take their allotments of the issue.

President Roosevelt has apparently caused some trouble in the financial world, but he is only taking up the people's cry for investment protection. He has aimed no blows at the honest banker or the honest security dealer. He has not only exposed the nature faker, but has paved the way for the glaring exposure of the security faker.

The word *"bond"* at one time had a well-defined meaning. "Is it not so written in the bond?" gloated the wily Shylock in demanding his pound of flesh. The word implied bondage, slavery, burden, and other terms so dreadful to the human race.

Most of us have a childhood recollection of the mortgage on the farm. It was a gloomy presence and cast sinister shadows over our youthful pastimes. It filled our hearts with dread. At Christmas-time, even traditionally kind Santa Claus passed us by, because he too dreaded the mortgage; so the whole family struggled with a sickening fear. And why? Because a first mortgage upon that home was and is a safe investment—a real security for the holder. It holds the property at a sacrificial figure. The value of the farm exceeds considerably the face value of the loan. The terms of that mortgage are such that the family will not think of giving up the property, but manfully struggle to meet payments when due. At no time is the holder of that mortgage uneasy; but in the general security market, the shoe is on the other foot. The word no longer signifies the slavery and bondage of the property, but mostly signalizes the folly of the holder.

We all know of properties that are bonded for more than their value and earning power and each day we hear of companies defaulting on interest.

The widow who once looked hopefully forward to coupon-clipping time and the return of the check, now has reason to

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*Since this paper was originally printed, a valuable paper by William B. Jackson on Depreciation and Reserve Funds of Electrical Properties was presented to the Society and published in the Journal, Vol. XV, p. 587, October, 1910.

dread a notice coming through the mail, accompanying her coupons, informing her that a receiver is in control of the property and that her investment is hopelessly tied up; or, more futile still, that a committee has been appointed to investigate what caused the wreck. It is the old story of locking the barn door after the horse is gone.

Some bankers, whether conscious of it or not, have been and are security fakers. There are savings banks which, in paying 3% to frugal depositors, try to create the impression that they are public benefactors. Scattered about on their counters one may find prospectuses of bonds, telling alluringly of good things. The banker does not care to have the depositors' funds withdrawn, but if he can sell a bond at $100.00, netting the frugal depositor 5% instead of 3%, and netting him $35.00 or $45.00, of course, he willingly advises the depositor to buy it.

If this banker would carefully investigate the property he might not find it desirable. He might find that there was no contract regarding its management. He might learn that there was no provision for an honest renewal-reserve. The worst of it is, judging from security prospectuses seen lying around, he does not care. He simply sells bonds at a profit, washes his hands of the deal, and denies that he is his brother's keeper.

We have a feeling of indignation when we read of the abandonment of a helpless infant upon a front doorstep, the persons involved taking no more precaution than to ring the bell. We exclaim how heartless, how unnatural! Yet the man who sells a security and runs away after collecting the money deserves our indignation. He is an unnatural father and deserves punishment.

According to the "Square Deal," the banker who sells securities should father them. He should be responsible for them, and should be willing to buy them back at any time there is a hitch in interest payment, or any entanglement thereupon.

There is a banking house in New York which handles immense issues of securities. At one period of their successful existence, through misrepresentation on the part of an adviser, they got hold of a disappointing property. After selling thousands of dollars worth of securities, they discovered the erratic features of the deal. Did this concern make the usual whine that they "didn't know" and thereby and forthwith abandon the luckless buyers to their fate? NO, this house, situated in that alleged to be heartless and soulless Wall Street, promptly notified the buyers of the deception and paid them back dollar for dollar. In other words, this firm fathers the bonds they sell and this brings out the relation of the banker to the engineer.

If the banker does not wish to be deceived as to the worth of the property, he must have competent advice. Not only must the auditor go over the books, but the engineer must go over the physical property. He must understand the needs of the property, not only now, but ten or twenty years hence. He must thoroughly understand depreciation. He must be thoroughly familiar with the best operating methods, and able to judge exactly as to the competency of the management.

The engineer must be a business man. Engineering is a business and not a profession as some are determined to have it. The successful engineer may stand for ideals, but he bears in mind the natural demands of the banker and public, that the property receive sufficient money, pay out money, and, like the individual, save money for a rainy day.

This homely expression signifies the necessity of what is called the renewal-reserve. In all properties owned by security holders, there is a sacred necessity which lies in the saving of enough money out of the daily or yearly income to take care of all changes in the art, all destruction due to the elements, and to hold the value of a $100.00 security at $100.00, or over, for all time.

As the property wears out, it decreases in value. Assume that, in a certain time, it decreases to a value of 90c on the dollar. Then the security owner is entitled to be assured that the necessary 10c is in the reserve treasury and available for the purpose of holding the value at 100c on the dollar; in other words, that the security holder may be sure that there will be no assessments, nor cessation of dividends, to take care of depreciation.

The renewal-reserve charges should come ahead of the bond interest. If a property cannot pay renewal-reserve charges and bond interest simultaneously, there should be a default. A property that is not protected by a cash renewal-reserve is not a real conservative investment. Book reserves are of no value, and reserves invested in the property itself do not carry out the idea of security.

Railroads could invest reserve funds in tie property or coal lands, and carry out the idea nicely; and electric light, trolley, and telephone systems could safely invest reserve funds in the municipal bonds of their immediate locality and carry out the idea of absolute security; but this idea is rarely fulfilled.

The engineer takes the following part in a contract between the banker and the property management, after the questions of reserve and other details are settled. The contract should contain the following thoughts at least:—

"The engineer of the bankers shall be furnished every facility to inspect the plans proposed for construction of extensions and improvements, the contracts and prices paid for labor, material and incidentals connected therewith, and the work during its progress, in order that he may certify that the plans adopted are the most economical to produce the best results; that the prices paid are lowest consistent with first class work, and that the work has been executed within the terms of the mortgage. He shall have access to all operating departments, and shall be furnished with all desired information. He shall have power to make tests, and to criticize operating methods. He shall report directly to the bankers, and said report shall not necessarily be accessible to the active management of the property."

It is understood that the contract gives the banker power to act upon the recommendations, but that is another story. With such a clause as above, the banker has direct means of knowing accurately every vital point concerning the property he has so nicely described to the public. If the property management is niggardly with maintenance and repair, thereby rendering the contracted renewal-reserve fund insufficient, the banker can call a halt. If the management is extravagant in operation and conduct of the business, thereby endangering bond interest, the banker knows it before it is too late.

The day is coming when all public utilities will have to take a defined position. Through the medium of broad-minded state commissions, properties will be conducted differently in the future. They will have to meet public demands promptly. They will not dodge taxes. They will be responsible for their employes safety. They will have to co-operate with the municipality in beautifying the city. They will have to maintain renewal-reserves and be ordered to invest them by law.

Under the new order, securities will be guaranteed because the property has conformed to the commissions' orders. There will be many things required of the companies that would give the present directors and legal advisers apoplexy.

This tendency means simply a closer study of reserves. The state commissions are studying the matter with us, and as engineers we shall help them to arrive at good conclusions.

The panic of 1907 and the subsequent decline in business activity was not caused by President Roosevelt or the New York Stock Exchange. The recklessly run trust companies temporarily furnished the germ of over prosperity, and later their own game of imbecile finance paid the penalty.

Any security was snapped up by these concerns, and for a time they made fabulous profits; but the old saying, "Truth is mighty and will prevail" proved itself once more. Then followed a panic of distrust, ruin, and suicide.

But a new day is dawning. All things commercial will have to be satisfied with less profit, because lessened risks will be demanded. The sober-minded public which do the investing, will demand reasonable profit and absolute safety. The public will always have money to invest. There will always be a chance for them to invest. The public will always invest through the banker. The banker will have to practically guarantee his investment advice if he expects to survive. To do this, he will seek the engineer.

The investments of the public will be guaranteed in their fullest sense only when there is a wedded relation between the ideals of the banker and engineer.

DISCUSSION.

Mr. D. W. Roper, M. W. S. E. (Chairman): I feel certain that we have all been much interested in the paper presented this evening by Mr. Kelsey. In all engineering work there are, we might say, two prime requisites,—the engineer and the money. The banker, from his point of view, might classify these requisites as money and engineers. The author considers the subject principally along the line of the relation of the consulting engineer to engineering corporations, but in another sense we might consider that all corporations who regularly employ engineers on their staff are divided into two branches,—engineering and financial,—and the relations between those two branches of the staff are similar to the relations described in the paper between the banker and the engineer. The financial managers of the corporations are responsible to the officers of the company, and they in turn to the bankers or financial agents of the company. So, subjects are continually coming up such as are brought forth in this paper, and some of us have occasion to consider them day by day. The problem of making our investments safe, and convincing the financial branch of the institution that the recommendations presented are not only sound from an engineering point of view, but commercially sound, is always before us. It is only when there is such continuous and hearty co-operation between the two branches that the corporation can continue to be a successful one. If the engineers who are employed by the corporation regularly make mistakes of that kind, they will wreck the company, although possibly not so quickly as some false reports by a consulting engineer regarding a new proposition which has come up.

Mr. F. M. Davis, JUN. M. W. S. E. (by letter): We are all familiar with the popular conception that the banker is to high finance what the engineer is to natural resource. Both are promoters and both strive as best they can to gain a competence, but with the difference that the banker takes his profits out of the public while the engineer takes his out of the rocks. However, we have been shown very cleverly that there is a mutual relation, close and vital, between the two and that this tie is bound to strengthen as time goes on.

In asserting that "the banker will have to practically guarantee his investment advice if he expects to survive," I believe that Mr. Kelsey has made a correct forecast of the future, certainly a fair interpretation of the signs of the times and a true statement of what is really needful to the future prosperity of the country.

To this guaranty attaches the vital interest of the engineer, for without the element of liability and its consequent demand for mathematical certainty what need would there be for engineering analysis and skill? It is only responsibility and limitations that create a demand for highly skilled technical service.

Hence it is the duty of every engineer to so prepare himself for accurate analysis of the essential elements of development and operating projects that his report may safely be made the basis of a sound and valid guaranty for securities. He owes this duty to his principal. He owes it also to himself, for without this capacity he can never hope to·attain to any high degree of recognition in the practical affairs of the world.

In order to get results promptly an engineer must know exactly what, in a commercial sense, is essential, and he must be able to pick it out at once and separate it from that which would be of only scientific or perhaps doubtful value. This requires more than a plain technical training. The engineer should have a good working knowledge of general business methods including contracts, sales, and corporation finance.

I apprehend that these subjects, although treated to a limited extent already in some of the technical institutions, should in the future receive far more attention than they do at present. Such preparation will enable the engineer to proceed at once with intelligent regard for his principal.

Only by thus adapting his technical resources can the engineer hope to realize that "wedded relation between the ideals of the banker and the engineer."

Mr. A. Bement, M. W. S. E.: I think this is one of the most important papers that we have had presented for some time. I do not believe, however, that the subject can receive the attention tonight that it .merits, because it is somewhat new and is one that requires thought before it can be properly developed. I suggest that it might be well to again take up consideration of the subject at a later date.

Mr. W. B. Jackson, M. W. S. E.: I consider that this subject is a very live one at the present time and that it will become more important as the days and the years go by. There are several interesting statements made in the paper and there is much with which I cannot agree. As opposition usually tends to create discussion, I will briefly consider points on which I do not agree with the author.

I feel that bankers, as a class, are amongst our most honest, trustworthy, and conscientious men, but that frequently they have not recognized the importance of the engineer in their business and that the engineer has often not fully appreciated the importance of his services to the banker. Bankers sometimes believe that engineers can give them complete and intelligent reports upon important engineering projects, without the full consideration that such matters require, and engineers have not always been persistent enough in assuring them that such is not possible.

I do not agree with the author that "engineering is a buisness and not a profession." I consider that all of us may justly be proud of the engineering profession, and one important reason for this is that a man to be the best engineer must be a thorough business man. With a doctor, for instance, it is different; with the best of doctors it is only necessary that he should know what is the matter with his patient and to cure him. He need not be a business man to a greater extent than to be able to look after his own affairs, and even this is sometimes attended to by his friends. But a man may know about mechanics, draughting, and things of that kind, and he may have a good understanding of what is usually thought of as engineering, and yet be far from being an able member of the engineering profession, because he lacks business knowledge or ability, and consequently is not able to work hand in hand with the banker in accomplishing results. I will illustrate what I mean by considering a phase of the subject that has not been touched on very fully in the paper, although it has been referred to; that is, the work of designing and acting as supervising engineer in engineering works. I feel that a great many times engineering works have been seriously handicapped by the great gap that frequently exists between the engineer and the banker. The money that can be had for the completion of a project should have an important influence upon engineering work, and consequently the closer the engineer can be to the person in charge of the source of money supply the better he can plan his work.

There are many good projects wherein the amount of capital available for their construction makes it necessary for the engineer to use every endeavor to hold the first cost to the lowest possible limit, while at the same time producing a plant capable of realizing a reasonable net return upon the investment, after taking into consideration every operating expense and figuring upon a fair depreciation. There are also many projects wherein the only requirement is to produce a plant giving the greatest net returns upon the investment regardless of the initial cost.

It is necessary for the engineer to have a very broad grasp of such matters, and he must thoroughly understand the financial sides of the projects to enable him to obtain the best results.

It is thus seen that the engineer is not a worthy representative of his profession, unless he is able to appreciate the financial and business side of the problem as well as to design operative engineering works, and he must, consequently, be able to see the financial bearing of every move he makes in his work.

In the above I do not wish to disparage the importance of the promoter. It is true that in the past the promoter has frequently stood between the banker and the engineer to the detriment of engineering works, but one must not forget that the promoter (in the higher sense of the word) who is the enthusiastic germ of the great works of today is just as necessary as the banker or the engineer in producing these works. If we are to have this great middle-western and western part of our country energetically developed, as it should be, we should remember that the promoter has a right to expect fair returns for his energy, his enthusiasm, and his zeal in bringing projects to such a condition that they are worthy of the consideration of the banker.

I feel very strongly that this subject, of the relation of the banker to the engineer, is large enough and broad enough to deserve further consideration at the hands of the Society, and that we should thank the author for having made it the subject of his paper.

Mr. Roper: The remarks of Mr. Jackson called to my mind an instance of some years ago: A firm of consulting engineers were called upon to design an electric-light plant, to be installed in a city of considerable size where it would be in competition with the existing system. The engineers presented a paper describing the plant, and methods and principles to be used, and it was interesting to note that a statement was made in the paper that in designing the plant and considering the details and elements to be included in the plant, they had agreed in advance not to recommend any features on which they could not show a return of at least 18% per year. That was supposed to be sufficient to cover interest, depreciation, and a reasonable profit to the investor, and it not only gave them something definite to work by but something very definite to present to the people who were to invest their money.

Mr. E. N. Lake, M. W. S. E.: I believe that I am inclined to agree with the author of the paper and to disagree with Mr. Jackson in regard to the designation of the particular kind of bankers which the speaker of the evening evidently had in mind. It would, of course, be manifestly unfair to so style all bankers, because, as a class, we know they do not deserve such a designation.

I wish to mention as an example a case which came to my notice, and I will give some figures which, of course, are only for illustration.

A certain public-utility proposition was promoted, and we must give due credit to the promoter and his enthusiasm for a great deal of our railroad and public-utilities development. The work was done by a construction company,—not a construction company in the broad sense, but one of those temporary construction companies which are peculiar to a certain class of development operations, a company whose officers are either dummies, or are identical with those of the parent corporation. This work cost, we will say, $3,000,000. It was turned over to the parent corporation which had the undertaking in hand for, say, $3,500,000. The proposition was taken up by the bankers and brokers who floated an issue of $4,000,000 in bonds. I presume that the speaker of the evening, in referring to securities, refers more particularly to the bonds. We must not, however, lose sight of the stocks. On the undertaking I have just referred to there were issued, we will say, $2,000,000 in preferred and $4,000,000 in common stock, or a total of $10,000,000 of bonds and stocks against an actual cost of $3,000,000, or more than three times the cost of the property.

If this is a typical case, is it any wonder that the investing public are uneasy about the safety of their investments and are slow in buying new securities. Instead of attributing this uneasiness to the actions of our national executive, as has been done by certain interests, should we not consider it as a national crisis requiring the timely co-operation of the statesman, the banker, and the engineer to work out methods of supervision and control which, without unduly retarding development, will protect the investor?

Mr. Kelsey: In my paper I am referring to bonds as securities. The common stock I term *insecurities.* I tried to make it very plain that I am not looking at this matter from a construction standpoint. I was considering a property already in running order—an operating property.

Mr. J. R. Cravath, M. W. S. E.: I was especially interested in Mr. Kelsey's reference to the new order of things. There seems to be coming upon us the control of public-service corporations by state commission. We now have several examples of that control in this country, and the system seems to be working well so far, and probably will as long as state commissions rely on competent and honest engineering and expert advice. There is no doubt but that the publicity that usually accompanies state commission control of public-utility corporations tends to make the investments rather more secure and more attractive to the investing public, although they may not be quite so attractive to the promoter who wants to make big profits. It will also tend to stop a practice that has been quite common, especially in connection with electric-light and power corporations in the smaller towns: namely, that of putting whatever profits are earned back into the property, and gradually letting the property acquire a larger value without paying dividends, so that at the end of a term of years it would appear that the property had not been paying anything, when, as a matter of fact, it had.

Mr. Lake: In regard to the matter of stocks: It seems to me that the value of the stocks of any corporation is largely a matter of earning capacity. As an illustration of this, suppose that I go into the suburbs and buy a lot and erect a house which I value at $5,000, and which rents for $50.00 a month. Other people follow my example and build up around me and gradually my property becomes more valuable; after a while other properties in the same neighborhood of about the same class as mine are selling at $10,000 and renting for $100.00 per month. It is therefore perfectly legitimate for me to value my place at $10,000 and to place the rent at $100.00 per month, although I have not put another dollar additional investment into that property. That is a legitimate increase in my stock, so to speak, or call it "water" if you will.

Now, if a property has an earning capacity of 10% on its stock, it seems to me that it is likewise perfectly legitimate if, instead of issuing $100,000 of stock and paying 10%, the corporation issues $200,000 and pays 5%, providing it is done under proper supervision so as to protect the investor.

As to the bonds. These should, I believe, represent a much higher grade of investment, and, in case of public-utility companies, the charges made by the corporation to its capital account should be supervised by a commission or by some supervising body which may be given this control in the interests of safe financial methods.

This matter of control or supervision, such as we have here in Chicago in connection with our local traction situation, is a long step in advance.

The idealist believes that government or municipal ownership is the only solution. When I was in college that was my belief and I took part in a debate in which we showed conclusively how the railroads could be purchased at cost to construct new, bonds could be floated to raise the purchase price, and by economies in a central operating organization reduce fares and at the same time pay interest and principal in fifty years. The hard headed old judges of the debate could not see it that way, and our side lost. We were basing our arguments on ideal conditions,—ideal sociologically and ideal economically.

Some years afterward I came in more or less direct contact with practical municipal ownership in a city west of the Mississippi River, and saw how it worked under actual sociological and economic conditions. It is needless to say that the ideals of my old college debate were somewhat shattered.

But we are moving forward; we have had years of private ownership and private operation. Now we are having, right here in our local traction situation, a partnership of the municipality and the private interests under direct municipal supervision. Next we will probably have in our system of subways, municipal ownership, private operation, and municipal supervision. Then some day just before the arrival of the millenium, we may reach the ideal conditions of our college-day dreams and will have municipal and government ownership and operation of all public utilities.

Mr. Roper: Mr. Cravath has referred to the practice of some companies putting the profits back into the plant. There are many who contend that a strict account should be kept of the investment and operating charges,—that they should be carefully segregated,—and I think that is generally accepted now. There are many cases, however, where this is not done, as hinted by the speaker mentioned, and in many cases the true value of the property is concealed by the bookkeeping methods. Some years ago, at an electric-light convention in this city, a man who at the time was busily engaged with capitalists in securing control of a number of public-service corporations in this part of the country, commented at some length on that point, and told how, in the past few years, he had acquired about twenty-five corporations of that nature, and that the very inadequate system of accounting used by some of those companies enabled him to secure control at a price far below what they were worth.

Mr. E. F. Smith, M. W. S. E.: I have been impressed with the thought, during the discussion this evening, of the magnitude of the new field which perhaps is about to open, especially to consulting engineers, in this new relationship, and which should result in a large increase of prestige of the engineering profession. I think it also emphasizes to those of us on the engineering staff of large corporations, that we must bear in mind these things and study them closely in our constant daily responsibilities and relationships with our companies, along the lines indicated earlier in the evening.

I want to say that I greatly appreciate this paper that Mr. Kelsey has presented to us, as I am sure we all do, and I hope that some good results may come from it.

Mr. Samuel G. McMeen, M. W. S. E.: One becomes accustomed to think of the relation between banker and engineer as merely a coöperative one, in the ultimate service of the public, the engineer undertaking to design and construct a useful property, and the banker to gather the money to pay for material and service. Anything which will make this coöperation more comfortable is an advantage and it has seemed to me that there is a steady improvement in that way. There are still financial men who consider the engineer a necessary evil; but, for the matter of that, the world still has many people who cling to foolish notions. It is of comfort to note that financiers of the broadest experience and the largest success appreciate most fully engineering service, if it be thorough and decisive.

Mr. Kelsey's view of the present methods of finance impress one as being somewhat gloomy. Some of us are accustomed to consider such present practices, as may be below standard, as being due to the growth of the country in population and activity rather than to a growing rascality among financiers. It is to be hoped that those of us who think in that way are not entirely wrong.

In such a view, one is the more inclined to endorse the general tenor of Mr. Kelsey's prophecy of what may come about in the way of public guidance of the public's service. If such a method of investigation and control shall be introduced, as Mr. Kelsey's paper suggests, it is obvious that it becomes the duty of every organization, such as the Western Society of Engineers, to use its powers of influence in the direction of securing commissions not wholly lacking in a fair knowledge of the tasks on which they are to sit. The record of inquiry and recommendation by commission in this country to this time is far from satisfying.

CLOSURE.

Mr. Kelsey: I have been pleased to hear the different thoughts that have been brought out this evening. I have been engaged in this particular work for the last few years and have seen many attempts to defraud the public, and it is these things that we as engineers have to guard against. This paper deals altogether with the finished product. Sometimes, after a plant is nearly finished, it is discovered that more money is needed and that they need to refund, and it is the refunding that I am dealing with. Those who buy the new bonds are practically sure they know what they are buying. The interest on the bonds has been paid, and then if there is anything left, the common stock is entitled to some kind of revenue. I can name fifty plants that are paying bond interest nicely, and they are paying interest on their common stock, but they are neglecting depreciation, and some time they will have to stop. The idea I tried to convey in my paper is that the first duty to the plant is to provide for depreciation; bond interest is the second duty, and after that take the chances. The American people have been skinned beautifully in the last five years, not only in mining propositions, but in electrical and telephone practice; a great many propositions look good but are not good. If the engineering profession cannot make itself of importance, and make the people have confidence in it, the profession is going to lose its value. Almost all propositions are in its hands, or at least the engineer or engineering is at the bottom of most propositions.

THE RELATION OF THE ENGINEER TO LIFE.*

By John W. Alvord.

Retiring President of The Western Society of Engineers.

The Constitution of the Western Society of Engineers prescribes that, among other duties, the President shall make an annual address to the Society.

This simple injunction, framed in mild language, has nevertheless a sinister aspect, for it takes no account of the problem as to whether the President is capable of undergoing such a strain. It is true that we have had Presidents who were poets, and others that were orators, and even some that would have perhaps graced the ministry, and the task of making an annual address would naturally sit lightly upon those so favored by nature. But the majority of engineers are neither poets nor orators, and the task of climbing out of the valleys up to the hill-tops above the mists of detail, to gain some clear vision of the broader life of the engineer is indeed an arduous one.

Years ago, when I knew more than I do now, I had the temerity to attempt a satire on the usual annual presidential address, and, in particular, to hold up to ridicule that somewhat overworked definition of the engineer, "as harnessing the forces of nature to the use of man." My punishment, though long delayed, has been none the less merited and sure, for I realize tonight, as I stand here before you, that if there is one occasion upon which we must needs feel reverence and sobriety, it is as we try to define the broader meaning of our work in life and its possibilities.

I have, therefore, after some thought, chosen to speak to you tonight on three reasons why our profession is an ennobling occupation, and three reasons why, in my opinion, many engineers, especially the younger men, do not rise to a clear conception of their opportunities.

The charm of life, that which gives it its zest and inspiration, is to do useful work for our time, our place, and our generation: to realize that we are needed in the progress of things, and even at times appreciated; to feel that we are pushing the world a little inch up-hill, and to receive as our reward, not altogether financial return, but as well, the sense of that indefinable indebtedness which all must feel toward a useful profession, that is to say, appreciation.

I know of no body of men of whom this may be more truly said than the profession of the engineer, and it cannot be impressed on us too strongly that we who are engaged in this useful occupation are fortunate in having a calling whose broader aims shall

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*An address at the annual meeting and dinner, January 11, 1911.

constantly buoy us up and tide us over the mishaps, the disheartening accidents, and the daily grind of a life work which is all too full of drudgery and detail, if we permit ourselves to forget its possibilities.

There are, I think, three well-defined reasons why the occupation of the engineer is an ennobling one, and of these three I wish to briefly speak.

First, the engineer is the original conservationist. It has quite recently been given to the politicians and to others of strenuous life to discover this fact,—that the engineer who has been at work since the days of Tubal Cain, is the true and original conservator of natural resources. Of this there can be no dispute. Where the work of the engineer exists; where his thoughtful predeterminative and creative task is properly allotted, and carefully studied, there is conservation, there is the elimination of waste, there is the precise application of the resources of nature for the use of man, with no undue loss. We must therefore as a profession consistently claim that we have been newly rediscovered, for we have always existed, and that the conservation movement in all its novelty and all its breadth and all its newness is but an effort on the part of society at large, properly led, to appreciate the calling and work of the engineer.

Everybody is agreed on the nobleness of purpose which has emanated this thoughtful conservation movement; everybody is agreed on the altruism which would save for our children and our children's children the great natural resources which Providence has placed at our disposal, and everybody is agreed that the work of preserving these natural resources, of properly utilizing them, of conserving them, is an ennobling calling. So much has been said on this subject recently that I think I need not unnecessarily dilate upon it. I congratulate the profession that we have been removed from our temporary hiding places and held up by the chief of all strenuosity to the gaze of an admiring and appreciative world and I trust that it will result in more cordial relations between ourselves and the public whom we serve.

Second, I wish to point out that the work of the engineer is an ennobling calling because he is what may be termed the missionary of science. There are indeed those among the engineering profession to whom has been given the opportunity to develop discovery in pure science in the course of their occupation; to advance our knowledge of natural law for the sake of truth itself without regard to practical application, and we cheerfully honor those who have had this high opportunity. Most of us must be content with the knowledge that it is our lot in life only to keep abreast of the discoveries of science, and be able to so usefully apply them that their benefits may reach the masses of people who would otherwise have no time or means or ability to grasp the treasure-house of truth directly.

In this work of bringing to humanity the benefits of scientific research, the engineer has had to make and will have to continue to make great sacrifices. First of all, he has to be an educator to contend with prejudice, with doubt, and with ignorance; to lead patiently and gently the mass of men to understand how best they may better their condition; to guide them against over-enthusiasm on the one hand, and impractical expenditures on the other; and to lead them into the enjoyment of all that science holds for them in ordinary advancement of life through the aid of their useful art.

In this work the engineer has penetrated the forest and the deserts, has lived the life of self-denial in camps, isolated from all useful environment; has burrowed in tunnels; has endured the hardships of cold and heat, and rough and uninteresting associates,—a veritable missionary of truth; courageous, animated with high motives,—though not always recognizing that;—stirred with feelings of usefulness to humanity,—though not always aware of even that,—but inarticulately expressing in his life of devotion the larger and deeper motives which come to the teacher, the soldier, the scientist, and the missionary of the gospel which cause them to forego the pleasures of wealth, society, and ease in that larger and nobler sacrifice which appeals so deeply to humanity because of its altruistic nature.

And not alone in the desert or the mountains are such sacrifices made, but problems of great populations and congested municipalities require the same patient effort in teaching the useful arts and enlightening men as to how they may wisely and comfortably live together. All this is the work of the engineer in the advancement of civilization. To improve the sanitation of our large cities, purify their water supplies, improve their transportation, and comfortably house vast populations in congested territory requires the utmost patience and tact in dealing with ever changing Boards, Councils, Corporation Officers, and those empowered with responsibility.

I cannot conceive of a more ennobling calling than that which I have here described, a calling involving the teaching of useful scientific truth to the mass of men, of educating humanity to the possibilities afforded by the adaptation of science to daily life.

And, third, I wish to point out that professional engineering is an ennobling calling, because the engineer is, in the higher aspects of his work, a creator. The highest development of nature is life, and the highest development of life is thought, and among the highest developments of thought is creative imagination. In this respect man stands alone in the universe, preëminent and conspicuous, Godlike in his attributes; to him alone is given the opportunity to conceive, to depict, to create, and then by slow, patient steps to convey this impression first upon the paper, and then step by step carefully to transfer it to reality in the structure.

A thought must precede every useful act. The mason who lays a brick must either consciously or subconsciously imagine that brick in its proper place before the reality can be attained. The carpenter must have a constructive thought before he drives a nail;

he must conceive a method before he raises a roof rafter, and in like manner the architect must have a picture in his imagination before he makes a sketch for even the humblest cottage. So it is a necessary talent of the engineer, even in the humblest parts of his work, to preconceive, to originate, to design, to create, and in this respect he is on a par with the artist, the poet, the musician, or the writer. Yes, even more, because in all his work comes the element of a practical utility which makes it doubly useful and gives it tremendous meaning in the advancement of the fine art of living.

Now, I have said a good deal about the call of our profession to a better purpose, a good deal about its ennobling character, and the question naturally arises in the minds of all who duly appreciate all these things,—are we struggling toward these ideals? Do they lift us up, and if not, why not? It is a wise man who knows how to examine himself for his deficiencies, and it is not unfitting or improper that a profession should at times become introspective, and demand of itself, as would an individual, to know if it is fulfilling the call to high motives.

I have asked a good many of my friends during this past year why the profession of civil engineering did not turn out more marked men,—men of broad capacity; men of high ideals; men of large affairs. Many have answered me that it does, and this must be admitted in a large degree, and yet the question comes, why not in a larger degree? Are there any real reasons why we are hedged in, down-trodden, not appreciated, and do those reasons lie within or without the domain of our own endeavor?

Classifying some of the discussions which I have had on this subject, they resolve themselves, it seems to me, into three major reasons why the engineer does not always lay hold, to a larger degree, upon the inspiration and opportunity of his calling. These reasons are, first, that he naturally and necessarily so immerses himself in the details of his work that he cannot always get the broader outlook, the higher culture, that would come from an enlargement of his field of view. It is natural and proper, in a profession which is so exacting in its details, that the young man particularly should busy himself to an unusual degree with the accumulation of data. He must master these if he would get up to the next step in the ladder. They are the stepping stones by which he grasps the broader principles, but it comes to men in later life, that, after all, the underlying principles are simple, and that all facts fall into easy classification when we understand the broader principles which underlie them, and at least from this point on it seems to me that the engineer should devote himself more and more constantly to general culture, to wider reading, the broader perceptions, to higher ideals than occurred to him or were afforded him in his first efforts to get an understanding of the life work which he has chosen. The engineer needs a wide horizon; he needs more study of human nature; he needs to know more about the science of organization, of political and social economy, of finance, of business, and of common sense. These portions of his equipment are not always taught in the college, nor are they usually impressed upon him until he comes into contact with men who notably possess them. They are a necessary part of the success of every man who would be a leader, and there is no reason why the engineer should not be a leader among men.

A second reason which I have gathered from much discussion of this subject, has been voiced, or might be voiced in the complaint that, as a body, the engineering profession (and especially sometimes the younger members who have not caught a glimpse of its ideals) is not always quite loyal to it. There are too many heartburns over the success of a fancied rival; there is altogether too much jealousy, especially among those who are struggling to get a footing. There is, above all, a considerable lack of appreciation of the value of association; engineers are not always prone to remember that they are part of a brotherhood, and that their predecessors and cotemporaries have put on record, for the benefit of their profession and posterity, a vast mass of information, without which we could do no useful work. We are all deeply indebted to those who have placed useful information on record, and we pay our society dues cheerfully to aid in this good work. If this sense of obligation could be deepened, especially among the younger men, it would, I think, go far to remove that lack of loyalty which some of us are apt to show in our relations with our profession. I am aware that there may be differences of opinion upon this subject, and there has been advanced the opinion that engineers, as a rule, work together more heartily and cheerfully than do most of the other professions.

I would point out that this seems to be true exactly in proportion as civilization in different parts of our country has advanced. In the older settled communities, it is especially true that there is great loyalty to the profession as a whole. In the newer communities this condition is coming to be realized, but it has not as yet attained that stage which should be desired. Further, it may be pointed out that it seemingly becomes the truer the older a man becomes. The younger men do not always see clear on this question of loyalty to their profession. To them there is a heartbreaking experience of patience and slow progress, for rapid financial rise in the engineering profession, or any profession for that matter, is not usually desirable. Experience must come with years, and with the years also comes clear and broader views of the elemental and underlying principles that must be our guide. Youth has but a peep into the vast world of knowledge which lies before it. The young man usually becomes embarrassed with the vast masses of details which apparently he must absorb. Later, fundamental principles dawn on him. Among others comes usually this recognition of his indebtedness to the profession that has recorded information for his benefit.

It would seem to me, therefore, perhaps fair to say that often with youth and often with lack of association and often in the newer civilizations there is somewhat lacking that loyalty to the profession that would make its great ideal clearly perceived.

In the third place, many have suggested to me that one of the reasons why the engineer does not rise to an appreciation of his calling lies in the fact that he so often makes the mistake of placing the dollar ahead of useful service. This is a temptation which comes with peculiar force to the younger members of the profession, but alas many older men are not free from such fallacy. No more deadening or pessimistic view could destroy the noble aspects of a life work in anything altruistic than to have its success measured by salary or emoluments. Do not misunderstand me; it is right and proper for all of us to see to it that our work is worthily and properly remunerated. Self respect will not allow us to do otherwise, and we can all of us sympathize with the old darky preacher whose meager salary had not been promptly forthcoming when he said somewhat plaintively to his Sunday morning congregation, "Bredren and Sistern, things is not as they should be. You all must not 'spects I can preach on earth and boa'd in Heben."

To measure our success by financial remuneration; to set first in our imagination the amount which we are to receive for services over and above the best possibilities for usefulness, is a most fatal mistake. Nothing seems more pathetic than to see a youth measuring his job by the amount of money he can get out of it. He reminds me of the story of the two Hebrew gentlemen, who while traveling with their wives on a railroad train were wrecked, both injured and taken to a hospital. A month or two later they met on the street, and Mr. Cohen said, "Vel, Levy, how much did you get out of it?" "Five thousand dollars," said Levy. "Good for you," said Cohen, "das iss fine." "How much did you ged oud of it, Cohen?" said Levy. "Ten thousand dollars," said Cohen. "Mein Gott," said Levy, "ten thousand dollars and I only got five thousand; how did you do it?" "Dot vas easy," said Cohen. "Yoost as der accident habened, I haf der presence of mind to kick my wife in der shins."

Now I am afraid a good many young engineers who are continually looking about them for more pay, regardless of their usefulness in their present work, are, so to speak, "kicking their job *in the shin*."

Life, says a great poet, is the fibre with which the soul learns to weave.

Life is a study in adaptation; it is the development of character through our struggle with environment; that is to say, the effort to so order ourselves that we adapt ourselves to the laws of nature. To make nature serve our higher purpose is the first struggle of mankind. Second to this is the art of adapting ourselves to each other, through the science of human society. Through these two adaptations we strive, progress, achieve, and idealize.

We epitomize these adaptations in common language by describing the man who has in some manner attained them as having "common sense"; that is to say, the sense of common things which control us fundamentally.

Preeminently these are the cardinal principles of the engineer; his watchword; his diploma; his goal. Above all things, he is to keep his feet on earth; to be practical; to be conservative; to see all sides of his problem; to have the judicial mind; to find the path of least resistance whenever that path is an honorable one. This is "common sense." Sometimes it is called "horse sense."

I heard a story recently of a gentleman who lost his horse and offered a reward of $5.00 to any one who would find her quickly. A half-witted fellow in the town, after half an hour's search, returned, leading the animal by the bridle.

The owner, surprised at the ease with which the horse had been found, asked, as he handed over the money, "Tell me how you found him." "Wa'al," said the fellow, "I thought to myself, where would I go if I was a hoss; I went there and he had."

In conclusion, I would repeat again my text:

That the charm of life, that which gives it zest and meaning, is to do useful work for our time, our place, and our generation; to give more than we receive; to place usefulness ahead of emolument; to push the world a little inch uphill, and to plant a flower in everybody's garden but our own.

Gentlemen of the Society, we now come to the last sad rites of this administration. I feel, in retiring from the office with which you have favored me, that I have accomplished few of those things that I so hopefully started out to do. There is a tremendous field for usefulness as the head of such an organization as this. I feel instinctively that the next incumbent of the office whom you have selected will not find it difficult to outdo the deeds of the past administration.

One cold wintry morning a man of slender build was walking down a steep hill at a quick pace. There was ice under the snow which caused him to lose control of his feet. At a crossing half way down he encountered a large, heavy woman. The meeting was sudden, and before either realized it, a collision ensued, and both were sliding down the hill, the thin man underneath, the fat woman on top. When the bottom was reached and they came to a stop, these faint words came to the woman's ear, "Pardon me, Madam, but you will have to get off here. This is far as I go."

Gentlemen of the Western Society of Engineers, you will have to get off of me here. This is far as I go.

It now becomes my pleasant duty to turn over my high office to a more worthy successor, to whom, from the depths of my heart and on behalf of the Society, I wish every success in the work which he now takes up.

Gentlemen, Mr. O. P. Chamberlain, your new President.

IN MEMORIAM

JOHN J. McVEAN, M. W. S. E.

Died August 21, 1910.

John Jay McVean was born June 13, 1850, in Darien, Genesee County, New York. He was the second son of John and Isabella McVean, and a direct descendant of the clan McVean of Scotland.

He attended the public schools until he was 15 years of age and then, preparatory to entering college, attended the Free Academy at Rochester, New York, and the Rural Seminary at East Pembroke, New York. He entered Cornell University in the fall of 1869, where he continued his studies until May, 1872, when he left college to begin his engineering work.

His first engineering work was on surveys and construction of the Rochester and State Line Railway and continued until the panic of 1873 stopped the work. He then entered the service of the Erie Railroad as Assistant Engineer under Mr. R. Bell, Division Engineer, and was engaged on second-track work on the Susquehanna Division between Hornellsville and Corning, New York. In the fall of 1874 he entered the employ of the Rochester, Hornellsville and Pine Creek Railway as assistant on location, and was in charge of part of the construction work. Beginning in the spring of 1876 he served for two years as City Engineer of Lansing, Michigan: all of his subsequent work was in Michigan. He was engaged on the location of the Stanton Branch of the Detroit, Lansing and Northern Railroad in March, 1878, and later had charge of the construction and became the Chief Engineer in 1881.

In 1887-88 he located and constructed the G. R., L. & D. Ry. from Grand Ledge to Grand Rapids, Michigan, and in the latter year became also Chief Engineer of the C. & N. W. Ry., and as Chief Engineer located and constructed the Traverse City and the Chicago extensions of that road.

As an organizer Mr. McVean was preeminent. It is rare indeed to find such a loyal and efficient corps of assistants as he gathered about him during the years he was Chief Engineer of the above mentioned railroads. In addition to his routine duties, he undertook and carried to completion the resurvey and mapping of the entire right-of-way of the above roads, now the Pere Marquette System. The thoroughness with which his work was done, and the careful execution of the maps, made them models of their kind.

He was interested in local affairs, and in 1894 accepted an appointment from the Mayor of the City of Grand Rapids as a member of the Board of Public Works. As a member of that body he took an active interest and was rarely absent from its meetings during the three years of his term.

In 1900, failing health compelled him to give up all work. For the preceding two years he had suffered from arthritis, and his life had been almost despaired of. However, by his indomitable will and optimism, he recovered sufficiently to open an office and take up the practice of consulting engineer in 1906, in which capacity he designed and superintended the construction of several bridges, designed a sewer system for Hastings, Michigan, and was consulted on projects of water-power development, paving, etc.

In 1909 he was selected by the City of Grand Rapids and the railroads entering the city to design a comprehensive system for separation of grades, in which capacity he was engaged at the time of his death, which was the culmination of the fight he had waged so patiently and heroically for twelve years against disease with its intense suffering.

Mr. McVean was a believer and a practitioner of the "square deal" long before it attained its present popularity. He was upright in all his acts and scorned the pretender and the grafter. To all those who were fortunate enough to know him, his life will ever be an inspiration.

He was married to Miss Rachel Shankland at Ellicottville, N. Y., in 1879, who, with a son and a married daughter, survive him.

He became a member of the Western Society of Engineers, October 3, 1882. He was also a member of the American Society of Civil Engineers, and served as director from 1898 to 1900. He was a charter member of the American Railway Engineering and Maintenance of Way Association, and a member of the Masonic Order, belonging to the Consistory and Commandery.

L. W. GODDARD,
GEORGE M. AMES,
Committee.

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS.

Annual Meeting, January 11, 1911.

The annual meeting (No. 727) and dinner of the Society was held in the Red Room of the La Salle Hotel, Chicago, Wednesday, January 11, 1911, convening about 7 p. m., with nearly 150 members and guests in attendance.

There was no formal business before the Society, but President Alvord read the names of those to whom the Chanute Medals had been awarded. The report of the committee on the awards will be found in the pages following this. President Alvord then called on the Secretary for parts of the annual report, showing the growth of the Society the past year, the list of those who had been taken from our membership by death, etc. The President then made his address as retiring from his office, which is printed elsewhere in these pages, after which he turned over to Mr. O. P. Chamberlain, President-elect, the administration of the Society for the year 1911. Mr. Chamberlain, in accepting the office, made a few remarks pertaining to the work of the Society, with which he had been connected in an official capacity for the preceding two years.

President Chamberlain then introduced the Honorable Charles E. Merriam, who addressed the Society on *Municipal Engineering*. Mr. George C. Nimmons was next introduced, who spoke on *The New Uniform Contract*. Mr. W. H. Finley, a Past President of the Society, was next introduced, whose topic was, *Has the Engineer Arrived?* which was full of happy and witty allusions in his own peculiar manner. Mr. T. W. Snow was the last speaker for the evening, who gave *The Last Word*, his remarks being very happy, yet full of good sound sense. The meeting adjourned before 11 p. m. and all expressed themselves as having greatly enjoyed the occasion.

J. H. WARDER, Secretary.

ANNUAL REPORTS.

SECRETARY'S REPORT.

Chicago, January 11, 1911.

To the Board of Direction,
Western Society of Engineers,

Gentlemen:

Of the affairs of our Society for the past year, 1910, I have the honor to report that increased activity and interest has been shown in the proceedings of the Society. The growth of the Society has been fairly good; the number of meetings held has been greater than ever before in the same period of time; an increased interest in and use of our rooms and library has also been shown.

Concerning our Membership:

Total membership December 31, 1909		1,085
Number of applications acted upon during the year	108	
Of which the number of transfers was	9	99
Number of members reinstated		2
		1,186
Deduct losses through deaths, resignations, dropped, etc.		67
Total membership December 31, 1910		1,119
Net gain in membership during 1910		34

This membership of 1,119 is classified as follows:

	Resident.	Non-Resident.	Total.
Honorary members	1	2	3
Active members	515	362	877
Associates	53	7	60
Juniors	128	51	179
Summary	697	422	1,119

Since the last Annual Report, the Secretary regrets to record our loss by death of the following members,—thirteen in all:

George H. Cooke, Terre Haute, Ind.	Nov. 28, 1909
S. W. McMunn, Chicago	Apr. 30, 1910
Charles F. Foster, Chicago	May 8, 1910
Richard Price Morgan, Dwight, Ill.	May 20, 1910
Samuel M. Rowe, Chicago	May 22, 1910
James C. Long, Wyanet, Ill.	May 26, 1910
Hugo Arnold, Wilmette, Ill.	May 29, 1910
George N. Eastman, Palm Springs, Cal.	June 14, 1910
J. J. McVean, Grand Rapids, Mich.	Aug. 21, 1910
Charles L. Gould, Chicago	Sept. 18, 1910
Octave Chanute, Chicago	Nov. 23, 1910
H. H. Meadows, Atlanta, Ga.	Nov. 23, 1910
Hymen Fridstein, Chicago	Dec. 24, 1910

During the past year there were forty-five (45) called meetings, which amounts to more than one a week for the ten months of the usual session.

These meetings are classified as follows:

Annual meeting	1
Regular meetings	9
Extra meetings, including two social meetings	35

In addition there was a Smoker given by the Entertainment Committee in the Society Rooms this past fall.

List of Meetings Held in 1910.

January 5th (No. 683). Bridge and Structural Section. *Some Special Features of Steel Construction in Connection with the New Northwestern Terminal.* Described by W. C. Armstrong.

January 12th (No. 684). Annual Meeting and Dinner at the University Club, Chicago. Addresses from the retiring President, Andrews Allen, and from the President-elect, J. W. Alvord; B. E. Sunny, on *The Engineering of Chicago;* the Honorable B. W. Snow and M. J. Foreman; L. C. Fritch, B. J. Arnold, and L. P. Morehouse.

January 19th (No. 685). Extra Meeting. W. R. Wiley presented his paper on *Centrifugal Pumps.*

January 26th (No. 686). Extra Meeting. Electrical Section in joint session with the Chicago Section A. I. E. E., when W. Lee Campbell described *Recent Development in the Automatic Telephone.*

February 2d (No. 687). Regular Meeting. *The Panama Railroad and Its Relation to the Panama Canal,* by Ralph Budd, read by the Secretary.

February 9th (No. 688). Extra Meeting. Bridge and Structural Section. *Reinforced Concrete Bridges for Track Elevation.* By G. E. Tebbitts, of the C., B. & Q. R. R., E. O. Greifenhagen, of the C., M. & St. P. Ry., and F. L. Thompson, of the I. C. R. R.

February 16th (No. 689). Extra Meeting. Report of Committee on *The Chicago Harbor Problem,* presented by A. Bement, Chairman.

February 23d (No. 690). Extra Meeting. Electrical Section in joint session with the Chicago Section A. I. E. E. *Some Suggested Improvements* *in Underground Conduit Construction for Large Transmission Systems.* By Edw. N. Lake.

February 24th (No. 691). Special Extra Meeting, held in Fullerton Hall, Art Institute. W. V. Alford gave an illustrated lecture on his travels in *The Highlands of South America.*

March 2d (No. 692). Regular Meeting. *Hydraulic Mining of Auriferous Gravels.* By J. W. Phillips, of Lewiston, Cal. Read by Ernest McCullough.

March 9th (No. 693). Extra Meeting. Bridge and Structural Section. *Some Unusual Problems in Building Design,* and *Underpinning a Factory Building.* By F. E. Davidson.

March 16th (No. 694). Extra Meeting. *Water Pollution and Water Purification at Jersey City, N. J.* Presented by C. E. A. Winslow.

March 23d (No. 695). Extra Meeting. Electrical Section in joint meeting with Chicago Section A. I. E. E. *The Diversity Factor in the Distribution of Electric Light and Power.* Presented by H. B. Gear.

April 6th (No. 696). Regular Meeting. *Earth Pressures,* presented by Charles K. Mohler.

April 13th (No. 697). Bridge and Structural Section. *Reinforced Concrete Trestles.* By C. H. Cartlidge.

April 20th (No. 698). Extra Meeting. J. Paul Goode, of University of Chicago, addressed the meeting on *European Harbors.*

April 27th (No. 699). Electrical Section in joint meeting with Chicago Section A. I. E. E. *Depreciation and Reserve Funds of Electrical Properties.* By Wm. B. Jackson.

May 4th (No. 700). Regular Meeting. *Rescue Stations in Illinois Coal Mining Localities.* By R. Y. Williams.

May 11th (No. 701). Extra Meeting. Bridge and Structural Section. *Missouri River Bridge at Mobridge.* By J. H. Prior.

May 18th (No. 702). Extra Meeting. *The Design of Storm Water Drains in a Modern Sewer System.* By J. B. Balcomb.

May 27th (No. 703). Extra Meeting. *Paints and Pigments.* By A. H. Sabin, of New York.

June 1st (No. 704). Regular Meeting. *Engineering Methods Applied to Coal Mining.* By Warren R. Roberts.

June 7th (No. 705). Extra Meeting. Electrical Section in joint meeting with Chicago Section A. I. E. E. *Economic Considerations Governing the Selection of Electric Railroad Apparatus.* By F. Darlington, of Pittsburg.

June 15th (No. 706). Extra Meeting. *Heat Treatment of High Speed Tools.* By C. P. Berg.

July 8th (No. 707). Special Extra Meeting. *Recent European Progress in Dirigible Balloons.* By W. A. Blonck.

September 7th (No. 708). Special Meeting. Organization of a Section of the Society in the interests of Hydraulic, Sanitary, and Municipal Engineering.

September 7th (No. 709). Regular Meeting. *High Pressure Water Service for Fire Protection.* By J. B. Sando, of Milwaukee.

September 14th (No. 710). Informal Meeting and Smoker. W. R. Patterson gave an informal talk, with illustrations, on *Travels in Japan.*

September 21st (No. 711). Bridge and Structural Section. New Building Ordinance for Chicago. The portion relating to Dead and Live Loads and Wind Pressure, etc. Presented by T. L. Condron for discussion.

September 25th (No. 712). Extra Meeting. *New Light on the Origin of Portland Cement.* By Alfred S. Johnson.

October 5th (No. 713). Hydraulic, Sanitary, and Municipal Section. Discussion of B. E. Sunny's paper on Engineering of Chicago.

October 12th (No. 714). Bridge and Structural Section. *Allowable Unit Stresses in Building Material.* "Piles and Foundations," "Timber," and "Structural Steel," discussed by Messrs. Strehlow, Condron, McCullough, Armstrong, Davidson, Winslow, Allen, and Dart. (Further discussion Building Ordinance.)

October 17th (No. 715). Bridge and Structural Section. Further Consideration of Building Ordinance. *Masonry and Reinforced Concrete* discussed by Messrs. Giaver, McCullough, Hoyt, Armstrong, Davidson, Finley, and others.

October 19th (No. 716). Electrical Section in joint meeting with Chicago Section A. I. E. E. Fullerton Hall, Art Institute. Dr. C. P. Steinmetz addressed the meeting on *Industrial Importance of Electrostatics and Electric Impulse Forces*

October 26th (No. 717). Extra Meeting. *The Use of Diagrams for Solving Engineering Formulae.* By Gordon F. Dodge.

November 2d (No. 718). Regular Meeting. Amendments to the Constitution presented and discussed.

November 9th (No. 719). Bridge and Structural Section. *Wind Pressure on Mill Building Bents.* By Albert Smith.

November 16th (No. 720). An informal meeting following an excursion in the afternoon to Gary, Ill. Special features of the plants of Dolese and Shepard Co., presented by Messrs. Buckbee, Bachtenkircher, Woodford, and Patnoe for the company.

November 23d (No. 721). Electrical Section in joint meeting with Chicago Section A. I. E. E. *The Surging of Synchronous Machines.* By E. J. Berg.

November 30th (No. 722). Extra Meeting. *A Trip to Hong Kong.* An informal illustrated address. By W. R. Patterson. Ladies invited.

December 7th (No. 723). Regular Meeting. *Entropy.* By G. A. Goodenough.

December 14th (No. 724). Extra Meeting. Bridge and Structural Section. *The Reconstruction of the Pecos Viaduct.* By W. H. Anderson.

December 16th (No. 725). The Entertainment Committee gave a Smoker in Society Rooms with some professional entertainers.

December 21st (No. 726). Hydraulic, Sanitary, and Municipal Section. Fullerton Hall, Art Institute. *The Chicago Plan,* presented by E. H. Bennett. Ladies invited.

December 30th (No. 727). Special business meeting of Electrical Section to nominate officers for the Section for 1911.

A little more than a year ago, in November, 1909, there was organized a Section in the interests of Bridge and Structural Engineering. A new Section was organized in September, 1910, in the interests of Hydraulic, Sanitary, and Municipal Engineering.

The meetings of the Electrical Section—the first Section formed—are held jointly with the Chicago Section of the A. I. E. E. and are well attended. Some excellent and notable papers have been presented and discussed. The meetings of the other Sections have also been of interest and well attended.

The usual annual cleaning of the rooms, fresh calcimining of the walls, etc., was done during the summer. A complete re-seating of the Assembly Room has been accomplished at a cost of $332.50, which adds greatly to the appearance of the room and seating capacity. There has been added, also, a handsome chair for the use of the presiding officer—the gift of President Alvord.

Among the prominent members who have been taken from among us is our Honorary Member and Past President, Octave Chanute. For many years he was closely identified with the interests and welfare of our Society. He was elected President of this Society in 1901, and that same year Mr. Chanute gave the Society $100.00 to be used in the making of a set of bronze medals to be awarded to members of the Society, the writers of the best papers in Civil, Mechanical, and Electrical Engineering. When Mr. Chanute completed his year as President, he gave the Society $1,000.00 to be known as the Chanute Medal Fund, the interest of which was to be used in preparation of these prizes each year, and they have been so awarded since then.

For the year 1909 the award of these medals is as follows:

In Civil Engineering, to A. Bement, for his paper on *The Illinois Coal Field.*

In Electrical Engineering, to R. H. Rice, for his paper on *Low Tension Feeder Systems for Street Railways.*

In Mechanical Engineering, to O. Chanute, for his paper on *Recent Progress in Aviation.*

To our regret the medal award to Mr. Chanute can only be transmitted to his family, but the recommendation of the committee on this award was made prior to Mr. Chanute's death.

Another notable loss from among us was the death of Richard Price Morgan. We have been advised by his son, Dwight C. Morgan, M. W. S. E., that the family has given the Society the engineering library of his father, gathered in the sixty years of his practice as an engineer. These books have not yet been received, but are in preparation for transmission to our library.

In addition to the above gift, Gen. William Sooy Smith, a Past President of this Society, when about to move to Oregon, gave the Society his engineering library, to be disposed of as the Board of Direction may deem best. Among these books are some duplicates of what we already had on our library shelves, but a valuable addition to our library was 170 bound volumes of the French publication, Annales des Ponts et Chaussees from General Smith's gift. These make our file of this publication almost complete.

The value of our library for reference purposes is shown by the increased use of it.. It is *a free, public reference library,* and as such is the recipient of most of the U. S. Government publications of interest to engineers.

During this past year the Amendment Committee has given much time to the preparation of sundry amendments to the Constitution and By-Laws, with the object of codifying and correcting these instruments, and condensing the results into one completed instrument. The committee asked for and received the best efforts of the Board of Direction in this work. The amended Constitution was presented at the regular meeting of the Society held November 2, 1910, when some minor changes were made; at that meeting it was ordered printed and sent out to the Active Members of the Society for their vote by letter-ballot. These ballots were duly canvassed by the Board of Direction and the result announced at the regular meeting held December 7, 1910. The ballots received were overwhelmingly in favor of the new Constitution.

In conclusion the Secretary begs to announce the decision of our Board of Direction to publish the Journal, beginning with this year, in monthly form (except July and August), to be issued about the 25th of each month. It is expected that this will make the Journal of greater value and interest to our members and all others to whom it is sent.

The Secretary looks forward to and hopes for an increased activity in and value of the Society, by its open meetings for the presentation and discussion of engineering papers, to be subsequently published in the Journal, and to this end asks the hearty cooperation of all the membership in the Western Society of Engineers.

Respectfully submitted,

J. H. WARDER,
Secretary.

LIBRARIAN'S REPORT.

January 11, 1911.

To the Board of Direction,
Western Society Engineers,

Gentlemen:

The Librarian begs to submit the following as his report on the Library of this Society for 1910:

Total number of books accessioned		7,815
Additions to the Library during 1910		357
These may be classified as follows:		
Number of volumes bound by the Society	135	
Number of bound books—gifts and exchanges	189	
Number of volumes bought	25	
Number of pamphlets accessioned	8	
	357	
The total charge against the Library Account amounts to		$446.16
This can be divided as follows:		
For services	$119.40	
For material additions to the library	326.76	
	$446.16	

In addition to the preceding, the Furniture and Fixtures Account amounted to $419.93. This includes 190 new opera chairs in the Assembly Room, the cost of which was $332.50, and a large sectional case of broad shallow drawers for maps, that cost $43.43.

Very respectfully submitted,
J. H. WARDER, *Librarian.*

TREASURER'S REPORT FOR THE YEAR ENDING December 31st, 1910.

January 3, 1911.

To the Board of Direction,
Western Society of Engineers,
Chicago, Ill.

Gentlemen:

I respectfully submit herewith, a statement of the treasurer's account for the year ending December 31st, 1910, as follows:

CASH STATEMENT.

January 1st, 1910, cash in bank subject to check		$1,691.41	
RECEIPTS.			
Dues	$10,121.43		
Entrance Fees	1,417.00		
Subscription to Journal	336.63		
Advertising	2,316.82		
Sales Journal	180.65		
Interest	482.88		
Journal Account	71.85		
Library Account	21.85		
House Expense	531.25		
Stationery, Postage and Exchange	77.70		
General Printing	192.10		
Furniture and Fixtures	16.50		
Chanute Medal Fund	50.00		
Investments	1,500.00		
Bound Journal	205.00		
Bills payable	1,000.00	$18,521.66	
			$20,213.07

EXPENDITURES.

Dues repaid	$ 4.00		
Entrance Fees repaid	10.00		
Advertising commission	22.50		
Interest	15.82		
Journal Account	5,243.88		
Library Account	446.20		
House Expense	4,750.00		
Stationery, Postage and Exchange	1,086.74		
General Printing	1,489.56		
Services, Secretary	1,800.00		
Furniture and Fixtures	419.93		
Chanute Medal Fund	24.75		
Investment Account	4.040.00	$19,353.38	
December 31st, 1910, cash in bank subject to check		859.69	
			$20.213.07

SUMMARY.

Statement January 1st. 1910—		
To credit of Western Society of Engineers	$ 6,875.21	
Chanute Medal Fund	1,274.00	
Arnold Fund	1,000.00	$ 9,099.21
Investments	7.407.80	
Cash	1,691.41	$ 9,099.21
Statement January 1st, 1911—		
To credit Western Society of Engineers	$ 7,309.59	
Chanute Medal Fund	1,274.00	
Arnold Fund	1,000.00	$ 9,583.59
Investments	9,723.90	
Cash	859.69	
	$10,583.59	
Bills Payable—		
J. H. Warder's loan	1,000.00	$ 9,583.59

Respectfully yours,
ALBERT REICHMANN,
Treasurer.

REPORT OF THE JUDGES OF ELECTION.

To the Board of Direction,
Western Society of Engineers,
Gentlemen:

The undersigned judges of election, having canvassed the ballots cast for officers of the Western Society of Engineers for the year 1911, have the honor to report as follows:

Total number of ballots cast	425
Total number of ballots rejected as irregular	11
Total number rejected as not qualified to vote on account of non-payment of dues	6
Total number of ballots counted	408
Number of votes cast for President—	
O. P. Chamberlain	218
P. Junkersfeld	181

Number of votes cast for First Vice-President—	
W. C. Armstrong	247
A Bement	152
Number of votes cast for Second Vice-President—	
C. R. Dart	200
G. T. Seely	192
Number of votes cast for Third Vice-President—	
Ira O. Baker	315
John F. Hayford	84
Number of votes cast for Treasurer—	
Albert Reichmann	393
Number of votes cast for Trustee for three years—	
W. M. Hughes	140
E. McCullough	142
M. K. Trumbull	109

Respectfully submitted,

F. F. Sinks,
J. H. Heuser,
R. G. Rosenbach,
Judges of Election.

Chicago, January 6, 1911.

REPORT OF THE COMMITTEE ON CHANUTE MEDALS.

Chicago, January 6, 1911.

To the Board of Direction,
Western Society of Engineers,
Chicago,

Gentlemen:

In compliance with your communication of October 5th, 1910, notifying us of our selection as a committee on recommendation for the award of the Octave Chanute Medals for the year 1909, we now beg to submit that we have given careful consideration to the several papers listed by you as having been given by members of the Society during the year 1909, and in view of all the associated considerations involved in the determination of those which seemingly possessed priority of merit, we name the following:

Civil Engineering—A. Bement, The Illinois Coal Field.

Electrical Engineering—R. H. Rice, Low Tension Feeder Systems for Street Railways.

Mechanical Engineering—Octave Chanute, Recent Progress in Aviation.

The selection of Mr. Chanute's paper was made prior to his death.

Respectfully submitted,

A. V. Powell, Chairman,
G. W. Scott,
Wm. B. Jackson.

BOOK REVIEWS

PRACTICAL STAMP MILLING AND AMALGAMATION. By H. W. Mac Farren. 5 by 8 ins.; 166 pages, including index. Mining and Scientific Press, San Francisco, 1910. Price, $2.00.

This is a convenient and handy book on the subject of extracting free gold from the ore by reduction in stamp-mills. The book claims to be, and evidently is, a thoroughly practical one, the author having evidently had much experience in such work. The author says that in his earlier days when first engaged in stamp-milling, he eagerly sought for literature pertaining to stamp-milling but was not successful in finding it. This book is an attempt to give such practical information, and it incorporates the author's own experience, supplemented by knowledge gathered from mill men and metallurgists. The book can be read understandingly by any one who has any knowledge of the construction and operation of a stamp-mill, and is full of detailed and practical instructions as to the management, or operation rather, of a stamp-mill working on gold ores. After going over the book, the reviewer feels a desire to renew some of his earlier impressions and revisit some stamp-mills, large and small, to apply, in thought at least, some of the instructions in this practical book—what to do and how to do it. W.

METHODS USED IN PRELIMINARY WORK ON CATSKILL RESERVOIRS FOR A 500-MILLION GALLON DAILY SUPPLY FOR THE CITY OF NEW YORK. A paper presented to the Brooklyn Engineers' Club, January 9th, 1908, by Mr. J. S. Langthorn, Mem. B. E. C. Pamphlet, 6 by 9 ins.; 158 pages, many illustrations, maps and tables. The Engineering News Publishing Co., New York. Price, $1.00.

This is an interesting account of the engineering work connected with the new water supply for New York City. While it is not an official report, it has been written by a member of the engineering force who had access to the records, and is very comprehensive. It is well worth studying to obtain a fairly comprehensive idea of the magnitude of the whole work. It is also of value to a student of survey work because of the information therein on how such work was performed, including methods of triangulation work, etc. Perhaps it is of as great value, in the manner of determining the sub-surface conditions of the tract, the digging of test pits, and the borings for determination of sub-surface soil, rock, etc. The successful construction and maintenance of a great retaining dam for the Ashokan Reservoir is primarily dependent upon its foundation, and this was very thoroughly explored by means of test pits, borings, core-drilling, etc. The drill-cores were carefully marked as to origin in the field and as to sequence of parts, so that a good knowledge of the rock, etc., below the surface was obtained.

Some readers who are engaged in survey work will find much of interest in the parts of the paper describing the field work, and details of triangulation and stadia surveys, methods adopted, and results obtained. Other readers more interested in hydrography will find herein some interesting studies as to the determination of the amount of water available. This means the rainfall, the run-off, the character of streams and their flow as determined by wier measurements, etc. Much of the real estate involved in this grand project was held by private parties and had to be purchased from the owner, either by private purchase or condemnation proceedings. The surveys for this work were very complete; plates and notes pertaining to this branch of the field work are exhibited. The paper does not touch upon any details of construction but is a valuable and interesting description of the preliminary work required for this monumental work. W.

CLARIFICATION OF SEWAGE. by Dr. Ing. Rudolph Schmeitzner, of Chemnitz. Translated by A. Elliott Kimberly, Columbus, Ohio. The Engineering News Pub. Co., 1910. 6 by 9 ins.; 113 pages, many illustrations in text and two folding plates. Cloth. Price, $1.50.

This is an interesting book, based on the practice of a number of plants in Germany, where the treatment of sewage before being turned into a running steam is regulated by governmental regulations.

The use of filters for the bacterial purification of organic matter is not considered; indeed, in many of the German plants care is taken to avoid septic treatment, as understood and practiced in many plants in England and this country. This disposal of sewage by dilution in a running stream is rational and has received marked consideration and study in Germany of late years. The result of such practice, studied at the plants of some fifteen towns and cities of Germany, is the basis of this admirable book. The book does not consider the great question of purification of sewage, but describes various methods of clarification—the removal of sand by means of grit chambers, and of floating material by means of screens. The saving of fat from various sources to be found in raw sewage seems to be of sufficient economic value in Germany that provision is made in most of the plants to save this material. It is obvious that the removal of such material from the sewage renders the effluent less objectionable to its introduction into running streams. But in all cases the volume of the stream flow should be many times the volume of sewage discharged into the stream to insure its thorough dilution. Also the best practice is to introduce the clarified sewage into the stream below the surface, preferably near the bottom where it may be thoroughly mixed with the flowing water.

The author does not describe in great detail the actual construction, proportions, and operation of the plants visited, but uses the facts collected in his observations for a broad and general consideration of clarification plants, with description of screening devices and their operation. The book is particularly useful to professional workers in this country in showing what is being done in Germany. The treatise is essentially of the engineering features and not chemical or biological. As such, however, it has a distinct value to sanitary engineers. W.

THE MECHANICAL ENGINEERS' POCKET-BOOK. A Reference Book of Rules, Tables, Data, and Formulae, for the use of Engineers, Mechanics, and Students. By William Kent, M. E. 8th edition, 1910. New York, John Wiley & Sons. 4¼ by 7 ins.; leather bound, 1460 pages, more than 200 illustrations, many tables. Price, $5.00.

"Kent," as it has been familiarly known among engineers for the last dozen years or so, has been a stand-by and in constant use, even though within the last half-dozen years there has been some complaint that the book was not up to date. This has now been corrected by the rewriting and publishing of this, the eighth edition. In this process of development the book has been increased, measuring as it does 1¾ ins. thick, so that the term Pocket-Book is a misnomer. But the busy, active engineer, when he refers to the book from time to time and finds therein the special information that he wants, will have no occasion to find fault with this increase in size.

The book naturally begins with Mathematics, Arithmetic, Weights and Measures, Algebra, Mensuration of Plane Surfaces and Solid Bodies, Trigonometry, Geometry, Calculus, and Mathematical Tables, occupying nearly 170 pages. Next follows: Materials, Strength of Materials, Alloys, Ropes and Cables, Springs, Riveted Joints, and Iron and Steel, covering over 300 pages. Mechanics is the next general subject and is followed by Heat, Physical Properties of Gases and Air, with Heating and Ventilation, which brings the matter up to the 687th page. Nearly 100 pages are given to

Water, under various sub-heads, followed by Fuel, Steam, Steam-boilers and other internal combustion engines; also Machinery for Transmission, Elevating, Conveying, etc. Considerable space is given to matters electrical. The book is by no means a text-book but a handbook for ready and frequent reference. A careful reading of the book by a student of engineering will give him a good deal of knowledge of engineering matters, in detail, though he would need to look elsewhere to become properly grounded in broad underlying principles, which would naturally be out of place in such a handbook. One point in the book is the naming of the source of information which makes easy the reference to the original article and its authority. It is interesting to find that these references to the papers of American societies number some 450, to American Machinist and Engineering News, 100 and 105 respectively, and to standard text-books, some 200.

As to the mechanical execution of making the book, the reviewer has no complaint to make. The paper is excellent—though thin, it is opaque; the ink is a good black; the type is excellent, and the tables and illustrations are clear and well printed. W.

Journal of the
Western Society of Engineers

VOL. XVI FEBRUARY, 1911 No. 2

THE USE OF DIAGRAMS FOR SOLVING ENGINEERING FORMULAE.

Gordon F. Dodge, M. W. S. E.

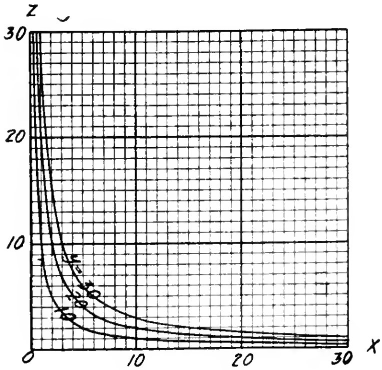
Presented October 26, 1910.

A review of the technical press for the past year or so, leads to the conclusion that the engineering profession in general is giving increasing consideration to the graphical representation of data and solution of engineering formulæ.

Notwithstanding this apparently increasing tendency towards the use of diagrams instead of inflexible tables, we in this country seem to be still considerably behind many foreign engineers in their application.

Although there have appeared from time to time many diagrammatical solutions of complicated formulæ, there seems to be a dearth of information as to the method of constructing such diagrams, and it is the purpose of this paper to show how easily they may be plotted.

Common coördinate paper, which is the most familiar, as ordinarly used, is limited to the expression of the relationship between two variables. The relation of three variables may be shown, however, by assigning a constant value to one of the variables and calculating the values of the other two throughout their working-range and thus securing a curve for the one particular value of the one assumed as constant; then assuming a new value for the constant and calculating a new curve, continuing to calculate and plot curves until all of the desired values of the third variable have been treated, Fig. 1. This in effect is the method of isometric plotting, Fig. 2, as used by some engineers, with the exception that rectangular axes are used and the curves on each of the imaginary parallel x z planes, Fig. 2, are projected onto the x z plane through the axis and parallel to the imaginary planes. Practically nothing is sacrificed in clarity of expression by this projection of all curves onto one plane. In fact the series of curves referred to two axes only, are more easily plotted and read than by the use of three series of reference lines as are characteristic of isometric paper, while the contours of isometric diagrams which are simply constant values of the vertical ordinate become, as would be expected,


z
30
20
10
y=30
20
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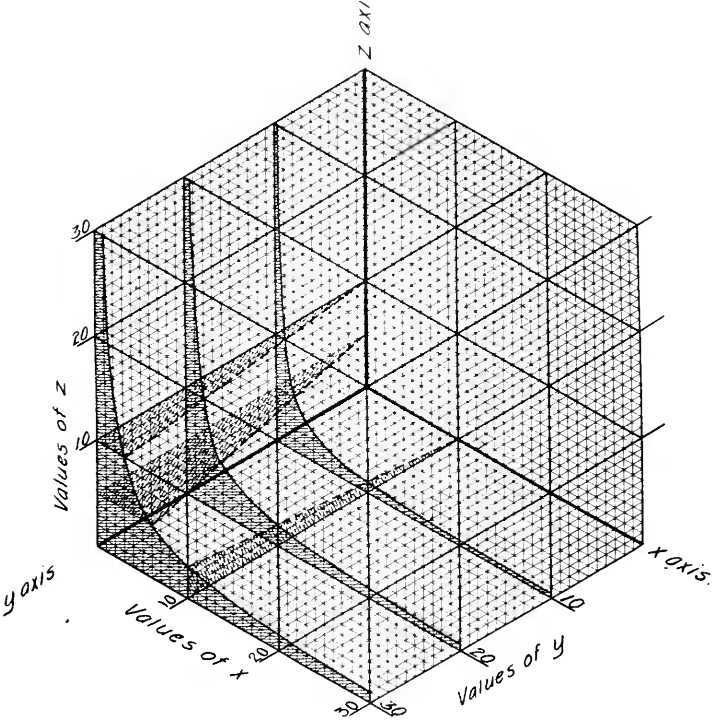
0
10
20
30
x

Fig 1.


Z axis
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Values of z
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Values of x
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Values of y
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20
30
x axis.

Fig 2.

nothing more than one of the ordinate lines of the group of projected curves.

In addition to the confusion attendant upon the three sets of reference lines, isometric paper is limited to the one condition of three variables. That this limitation does not apply even to ordinary paper, as might seem to be the case, will be seen later.

In some instances, as the comparison of the expansion curve of an engine, as given by the indicator, with the theoretical curve, the use of ordinary coördinate paper is indispensable. However, in almost all cases where paper of equal divisions has been used, paper with logarithmic divisions may be substituted to advantage, as it has a number of valuable properties that greatly simplify the task of plotting a series of results, and it is these particular properties that make it easy to use graphical methods of representing the relationship of more than three variables.

A few of these properties of logarithmic paper may be enumerated as follows: All expressions involving only simple multiplication or division give straight-line curves, and if the expression is of the first degree these lines will be inclined at an angle of 45° up to either the right or the left.

Take for example the familiar expression for moment in a cantilever beam loaded at the end, $M = Pl$. Assuming a constant length of 12 ft. for l, and plotting the values of this expression with M for abscissas and P for ordinates, we get the straight 45° line (*a*), Fig. 3, in which the inclination is up to the right. This direction of slope occurs in all cases except where the constant is divided by one or other of the variables (abscissas or ordinates).

Taking the same expression as before and assuming a constant M, the expression becomes, $P = \frac{M}{l}$, and when this is plotted with a value of M = say 1200 ft. lb., we have the 45° straight line inclined upwards to the left, (*b*) Fig: 3, showing the effect on the direction of inclination, produced by dividing the constant moment by the variable length.

The above stated conditions being general in application, regardless of the assumed constant value of the third variable, it follows that when the relationship between three variables of the first degree, involving only multiplication or division, is plotted, a series of parallel 45° lines will result. The reason of this parallelism at 45° is readily seen when it is observed that the origin on logarithmic paper is at infinity, and the increase in values of abscissas and ordinates is always up and to the right. As simple products and dividends (with some limitations) pass through zero (the origin), on ordinary paper, it follows that such lines must take the 45° inclination on logarithmic paper, and we have a graphical representation of the mathematical assumption that parallel lines meet at infinity.

This condition of no finite origin, gives rise to another decidedly valuable property, in that the percentage of error does not increase towards the origin as is the case with ordinary paper, but remains constant, thus eliminating the serious objection of inaccuracy at low values which is one of the evils of the ordinary diagram.

As is well known, an expression involving an ordinate or abscissa in any degree but the first, will, when plotted on ordinary coördinate paper, be represented by a curve. With logarithmic paper this is not the case. Expressions of other degrees than the first still give straight-line curves for all simple multiplications or divisions. If either the ordinates or abscissas alone represent a variable that enters in some other degree than the first, the line will make an angle with the axis representing this quantity, the tangent of which angle will be the same as the index of the power of the quantity.

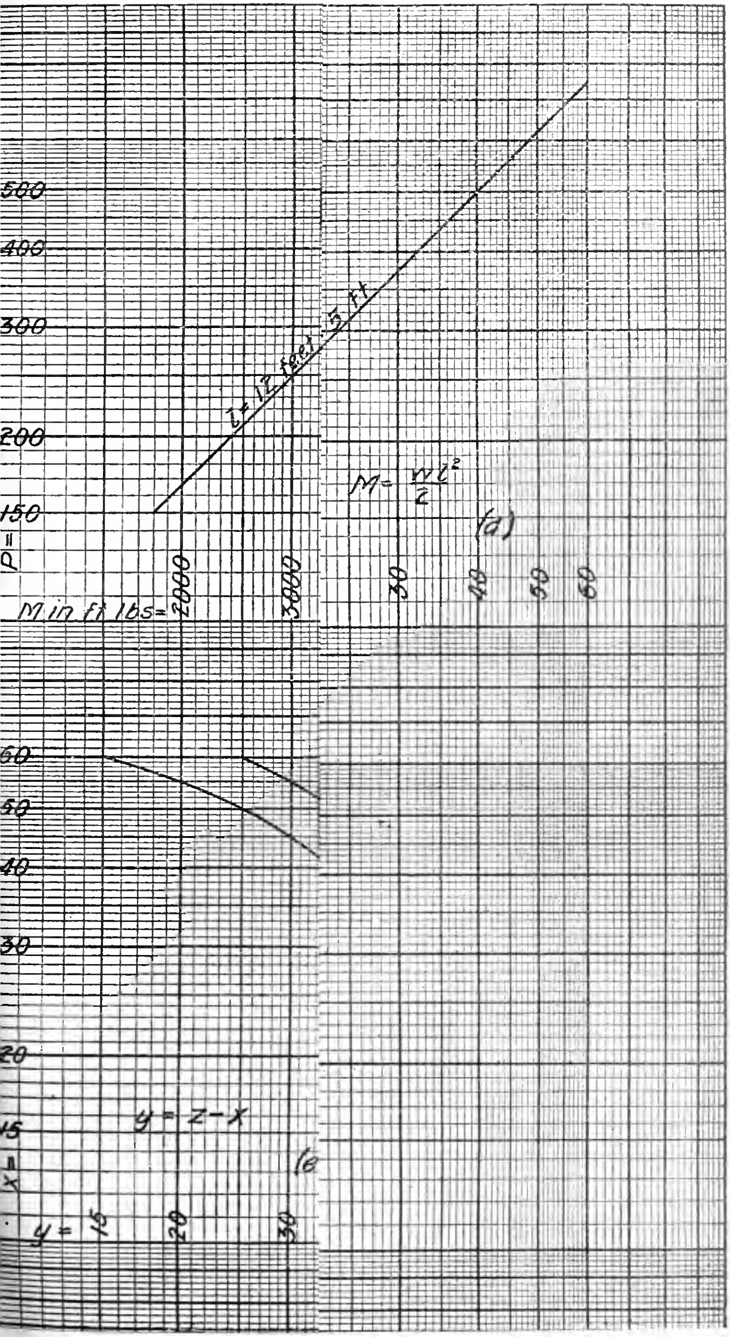
Consider again the cantilever beam, but with a uniform load per foot of length, we have, then, $M = \frac{wl^2}{2}$ in which the length l enters in the second degree.

Assuming a constant load w of 100 lb. per ft., and plotting with M as ordinates and l as abscissas, we get the straight line (c), Fig. 3, inclined upwards to the right, making an angle with the horizontal axis (representing the second degree quantity), the tangent of which angle is 2, the index of the degree to which the quantity is raised. The direction of slope will always be as explained in (b), Fig. 3, regardless of the degree of any of the variables.

If both the abscissas and the ordinates represent quantities of the same degree, irrespective of whether this is of the first or not, the lines will always be at an angle of 45° no matter what the degree of the third quantity, which is given a constant value for each curve of the set.

Taking the last expression plotted, $M = \frac{wl^2}{2}$, and using M and w as abscissas and ordinates, and plotting their relation for a constant length l of 5 ft., as in (d), Fig. 3, we have the condition of equal degrees for the quantities represented by the axes, and obtain the 45° line just as in (a), Fig. 3, where the constant was of the first degree, instead of the second as is the case here.

These good qualities of logarithmic paper, are accompanied by one of a somewhat negative character, viz., whenever a subtraction or addition enters the expression being plotted, a curved



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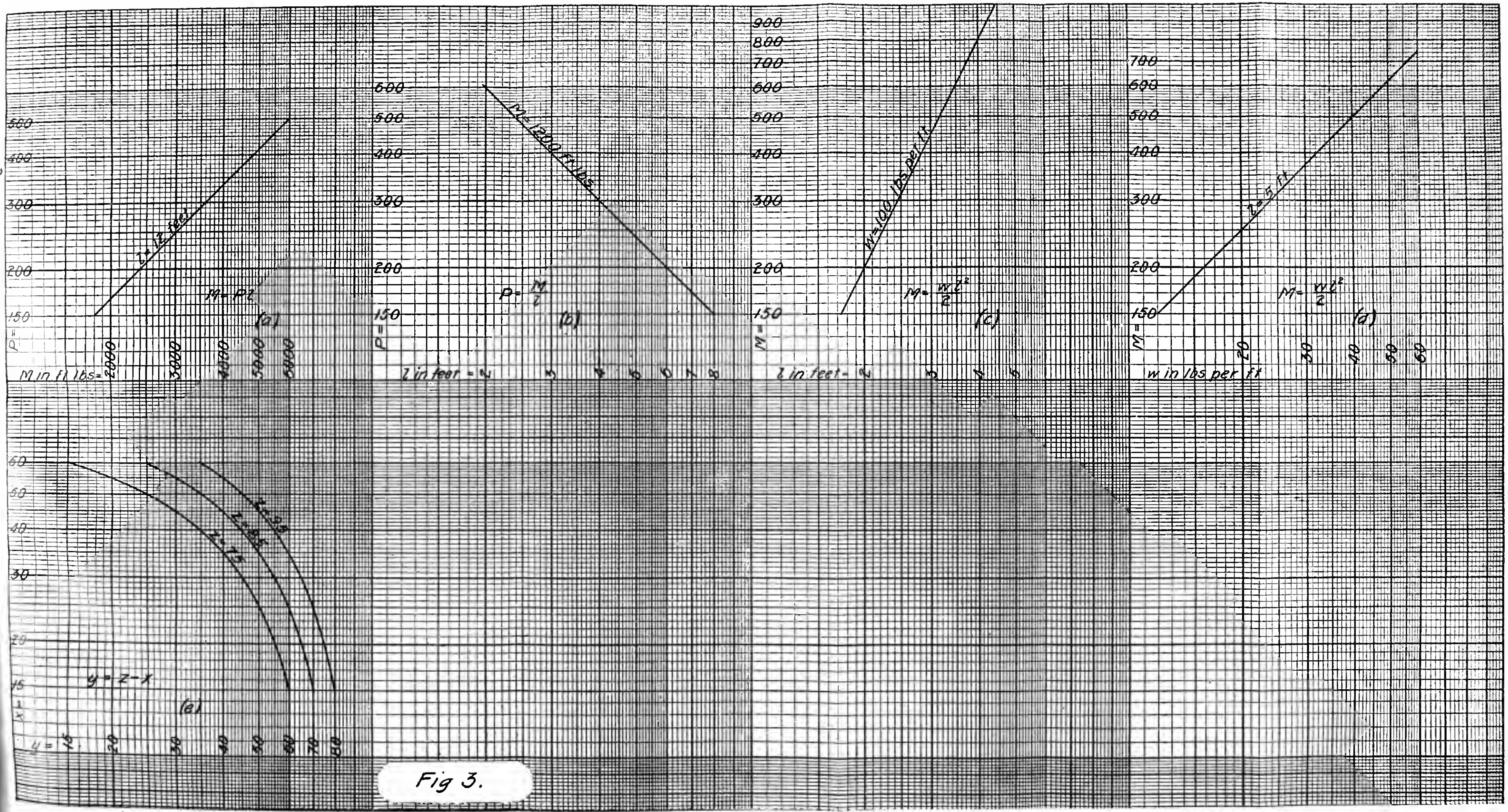
500
400
300
200
150
P =
l = 12 feet
M = Pl
(a)
M in ft lbs = 2000
3000
4000
5000
6000
600
500
400
300
200
150
P =
M = 1200 ft lbs
P = M/l
(b)
l in feet = 2
3
4
5
6
7
8
900
800
700
600
500
400
300
200
150
M =
w = 100 lbs per ft
M = wl²/2
(c)
l in feet = 2
3
4
5
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200
150
M =
l = 5 ft
M = wl²/2
(d)
w in lbs per ft
20
30
40
50
60
60
50
40
30
20
15
x =
z = 9.5
z = 8.5
z = 7.5
y = z − x
(e)
y = 15
20
30
40
50
60
70
80

Fig 3.

line results. Take the simple algebraic case of $y = z - x$ and plotting with the constant values of 75, 85, and 95 for z, the curves of (*e*), Fig. 3, result. Strange to say, this is the one condition under which ordinary paper will give a series of parallel straight lines when expressing the relationship between three variables, and even then the quantities used as abscissas and ordinates must be of the first or same degree.

It is only recently that logarithmic paper with graduations greater than from one to ten has been regularly carried by the supply houses, but now one at least of the better known houses carries paper graduated from one to one-hundred. This inability to readily obtain paper of wider range no doubt accounts, to a considerable degree, for the apparent unfamiliarity of engineers in general with its use, and in particular with its use in connection with the diagrammatical treatment of formulæ involving more than four variables.

As previously stated, any expression of three variables may readily be expressed graphically by assigning a series of constant values to one of them, and calculating a curve for each of these values. By taking advantage of the 45° parallel, straight line and other properties of logarithmic paper just explained, this task of calculating the curves is reduced to a minimum, as it is usually necessary to calculate but one point on each line—two, if a check on the work is desired—unless additions or subtractions enter the particular relationship being calculated.

As far as the writer has been able to learn, a fellow member of this Society, Mr. Edward C. DeWolfe, was one of the first to recognize and put to extensive use these valuable properties of logarithmic paper. Others have used it, but at the expense of clearness on account of having plotted two or more sets of lines upon the same space. Some of Mr. DeWolfe's work, as seen recently by the writer, indicates that he used much the same methods as those to be described later, the principal difference being that in his work, Mr. DeWolfe sometimes follows the diagonal lines, whereas the writer has found it to be easier and clearer to make all turns at right angles when reading the diagrams.*

Over eighteen years ago Mr. Carl Hering presented a paper before the American Institute of Electrical Engineers, in which he described a method of treating more than three variables graphically, using paper with equal divisions. The diagram presented by him at that time, and reproduced in Fig. 4, gives the

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*Since this paper was written the writer has become familiar with the extended work along these same lines, of two other members of this Society,—Mr. B. E. Winslow and Mr. W. E. Ramsey. At a recent meeting Mr. Winslow presented one of his unpublished diagrams, which bears a date of some ten years ago. Many of the diagrams which the writer has seen are a combination of tabular and diagrammatical treatment, and as such are unusually interesting.

solution, as indicated by the dotted line and arrowheads, of all ordinary wiring circuits. The general formula, cross section =

$$\frac{\text{Current for one lamp} \times \text{no lamps} \times \text{distance} \times \text{constant,}}{\text{loss in volts}}$$

contains five variables and one constant, all of the first degree. Even with all first-degree variables it is necessary, as Mr. Hering points out, that in plotting any three variables the one assumed as a constant must be a quotient of the other two and not a product, as the latter condition will result in hyperbolas instead of radial straight lines. As an illustration, consider the simple algebraic expression, $y = zx$.

If x and z be used as ordinates and abscissas, Fig. 2, and constant values of y be plotted, a series of hyperbolas will result, but if the expression be transformed into $x = \frac{y}{z}$, or $z = \frac{y}{x}$, and either expression plotted with the quantity which represents the quotient as a constant and the other two as ordinates and abscissas, a series of straight radial lines will result, as evidence the planes of constant zs and xs, Fig. 2, cutting the curved surface of constant ys.

Quite recently there have appeared several diagrams similar to this one of Mr. Hering's, Fig. 4, with one or two more variables added, but plotted with the several sets of lines superimposed on one another, as suggested by him, and having to a decided degree the fault he mentioned, viz., confusion due to the many sets of lines, and also in common with his diagram the element of an increasing percentage of error as the origin is approached.

The principles underlying the construction of diagrams of this class are extremely simple, the solution proceeding by steps as indicated on the diagram just given. The first requirement is that the equation be so transformed that all but two of the variables may be treated as one quantity. Until thoroughly familiar with the method of procedure, it is more convenient to arrange the surplus variables that are to be considered as one quantity on one side of the equation, and the other two on the opposite side.

THICK CYLINDERS.

For the first of a few examples of step solutions, the Lamè formula for thick cylinders has been selected, as it gives one of the simplest applications, in that there are but two steps required.

In the formula,

$$\frac{D}{d} = \sqrt{\frac{f+p}{f-p}}$$

D = the outside diameter of the cylinder, the fraction

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e that would
mplished by
values of p
this expres-
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000	12000	16000
500	12500	16500
00	11500	15500
105	1.087	1.064
05	1.042	1.031

of p curves

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Curves for
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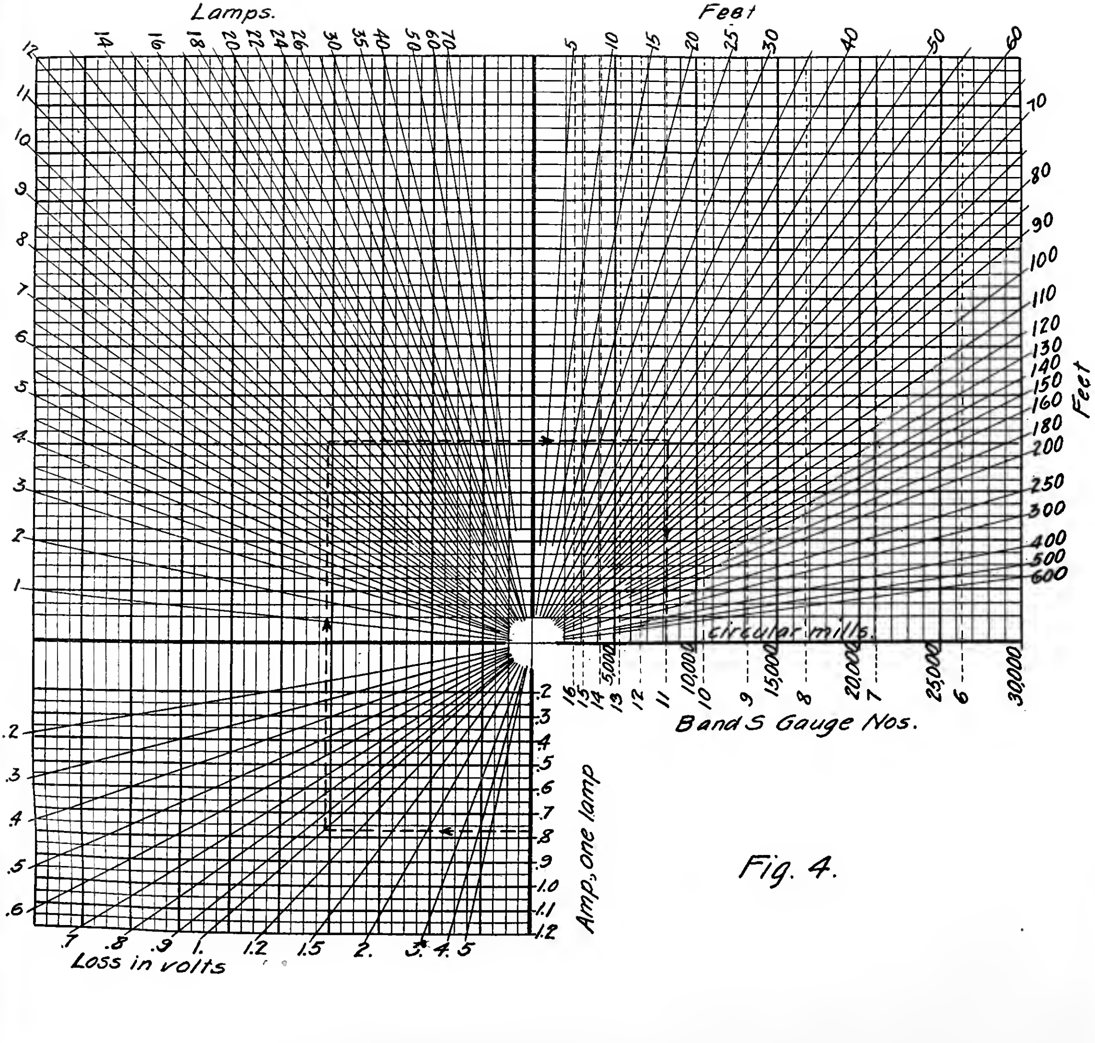
Lamps.
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Lamps.
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Lamps.
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15
14
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12
11
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9
8
7
6
B and S Gauge Nos.
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
Amp, one lamp
Loss in volts.
.2
.3
.4
.5
.6
.7
.8
.9
1.
1.2
1.5
2.
3.
4.
5
Loss in volts

Fig. 4.

$d =$ the inside diameter,
$p =$ the pressure inside the cylinder,
$f =$ the fiber stress in the metal.

The formula is already in the required form, the fraction $\frac{D}{d}$ being considered as one quantity. We begin then, by calculating the values of the expression under the radical for the various combinations of f and p throughout the range that would be ordinarily met with. This is most readily accomplished by compiling a table as follows, for each one of the values of p that it is desired to have the diagram show. Since this expression contains not only the sum but also the difference of the quantities, it will be necessary to calculate the value of the quantity under the radical, with several values of f, for each value of p, as it has been explained that with logarithmic paper a curve will result whenever sums or differences enter, and for the sake of accuracy the points should not be too widely separated.

p		f									
500		2000	2500	3000	4000	5000	6000	8000	10000	12000	16000
	$f+p$	2500	3000	3500	4500	5500	6500	8500	10500	12500	16500
	$f-p$	1500	2000	2500	3500	4500	5500	7500	9500	11500	15500
	$\div$	1.667	1.5	1.40	1.285	1.222	1.182	1.133	1.105	1.087	1.064
	$\sqrt{\ }$	1.29	1.224	1.183	1.133	1.105	1.086	1.064	1.05	1.042	1.031

From the above table the first one of the set of p curves of Fig. 5 was plotted, using f as abscissas and $\frac{D}{d}$ as ordinates, while p has the constant value of 500 lb. per sq. in. Curves for other values of p are calculated and plotted in a similar manner.

With the values of $\frac{D}{d}$ determined, a second table is calculated by multiplying these values by a series of constant values of d, which gives the values of D for various relations of d and $\frac{D}{d}$. As this operation is a simple multiplication without any sum or difference entering, the result of any series of products of $\frac{D}{d}$ multiplied by d will be a 45° straight line inclined upwards to the right, and it will be necessary to use but one value of $\frac{D}{d}$, as say two (2), with each value of d that it is wished to plot.

The heavy dotted meander line indicates the solution of a problem in which $f = 3000$, $p = 1500$, and $d = 10$ in., showing an outside diameter of 17.3 in. required, or a thickness of say 3⅝ in.

CENTRIFUGAL FORCE.

In the case of formulæ like that for centrifugal force,

$$C = \frac{wv^2}{gr}, \text{ in which,}$$

C = centrifugal force,
w = weight of moving body in pounds,
v = velocity of center of gravity of weight in feet per second,
g = acceleration of gravity,
r = radius in feet of the path of center of gravity of weight,

there enters a quantity v^2, which is, in the most common use of the formula, a product of other elements, and a separate calculation becomes necessary to determine its value from the quantities of which it is the product. As these quantities are those usually met with in calculations of centrifugal force, it is entirely feasible to incorporate into the diagram the solution for this quantity v as determined by its formula,

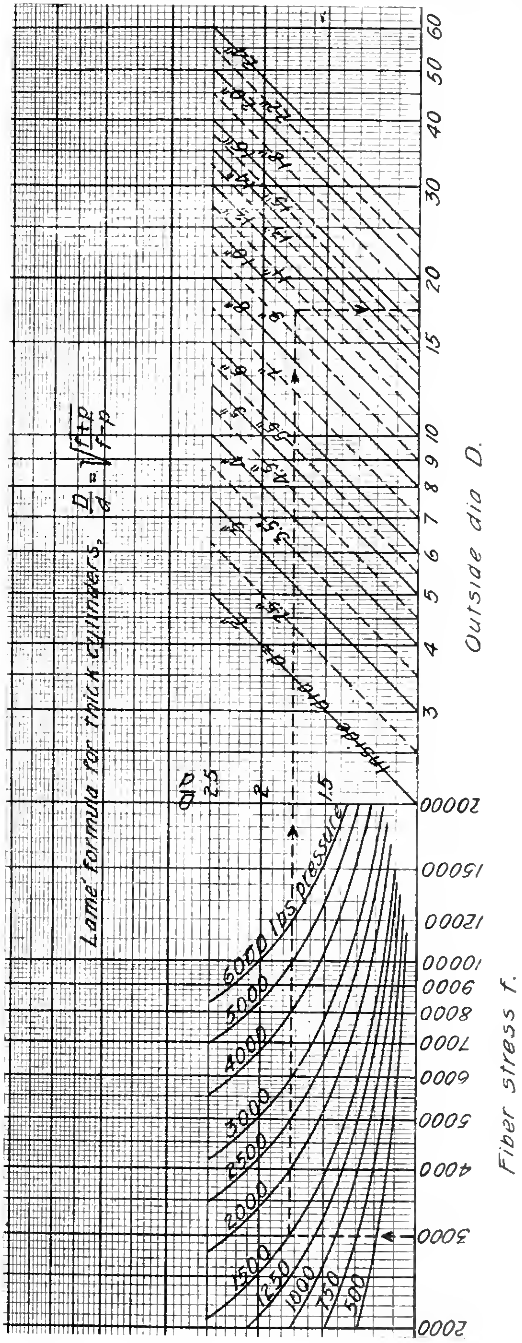
$$v = 2\pi\, r \text{ r. p. m.} \div 60 = 0.1047\, r \text{ r. p. m.}$$

As this expression is a simple product, the results of various combinations will be 45° lines, and it will be necessary to use but one value of r, as say 10 ft., in connection with each assumed r. p. m., in order to obtain the information with which to plot the first series of lines in Fig. 6, using r as abscissas and v as ordinates.

In the second step of the solution the equation is transformed into,

$$\frac{C}{w} = \frac{v^2}{gr},$$

the first part of the equation being considered as one variable and a table of values calculated for a constant value of v and a series of values of r. As g is a constant quantity, it will have the effect only of making a constant variation in the values of $\frac{C}{w}$ and will not affect the slope or curvature of the lines. It may therefore be included directly in the process of division. The quantity v enters the expression in the second degree, and as it is used as an ordinate, the slope of the series of r lines will, as previously stated, be such that they will make an angle with the vertical axis, the tangent of which is two (2), the index of the power of the ordinate. In other words, the r lines will rise


Lame' formula for thick cylinders, $\frac{D}{d}=\sqrt{\frac{f+p}{f-p}}$
Outside dia D.
60
50
40
30
20
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6
5
4
3
Inside dia. d=
D/d
2.5
2
1.5
Fiber stress f.
20000
15000
12000
10000
9000
8000
7000
6000
5000
4000
3000
2000
6000 lbs pressure
5000
4000
3000
2500
2000
1500
1250
1000
750
500

Fig 5

vertically from $v = 10$ to $v = 100$ while reaching horizontally from $\frac{C}{w} = 1$ to 100. With the slope known, only one point on each r line need be calculated.

With $\frac{C}{w}$ determined, and the r lines plotted with these values for abscissas and v as ordinates coinciding with the v scale of the preceding set of lines, the final step will consist of calculating a table of values of C from some constant value of $\frac{C}{w}$, by multiplying by a series of values of w. Obviously, values of w from 1 to 10 might be used, and the results plotted for this range only. In any particular solution then, it becomes necessary to multiply the final result as given by the diagram by the quotient found by dividing the actual weight by the value of the weight line used. That is, if the weight were 600, and the weight line used be 6, the result would be multiplied by 100; in other words, keep track of the decimal point, somewhat as with a slide rule.

The calculations involved in plotting the third step of this diagram being simple multiplication, the w lines will be straight, 45°, inclined upwards to the right. On account of the wide range, the series of w lines having values of from 1 to 10 would extend far beyond the vertical limits of the paper in covering all the values of $\frac{C}{w}$ (unit centrifugal force). To overcome this difficulty and remain within the limits of the paper, the values of w are increased up to 1000 in the lower portion of the diagram. The same principle of final results applies to these lines, as was stated before, viz., the multiplication of the marginal result by the quotient of the actual weight divided by the value of the weight line. In the solution indicated by the heavy dotted meander line, a weight of 560 lb. is rotating at a speed of 25 r. p. m. on a radius of 2 ft. 6 in. In this problem the abscissa of $\frac{C}{w}$ (unit centrifugal force) intersects a w line having a value of 5.6, and the marginal result given by the diagram will therefore have to be multiplied by 100, giving a final value of 300.

In any problem where the velocity is known directly and not as the elements of which it is a product, this known value of v may be used as the entering point, and the solution found exactly as though the first step had not been omitted.

With radii 10 or 100 times as great as those given on the diagram, the result as obtained in the usual manner will be

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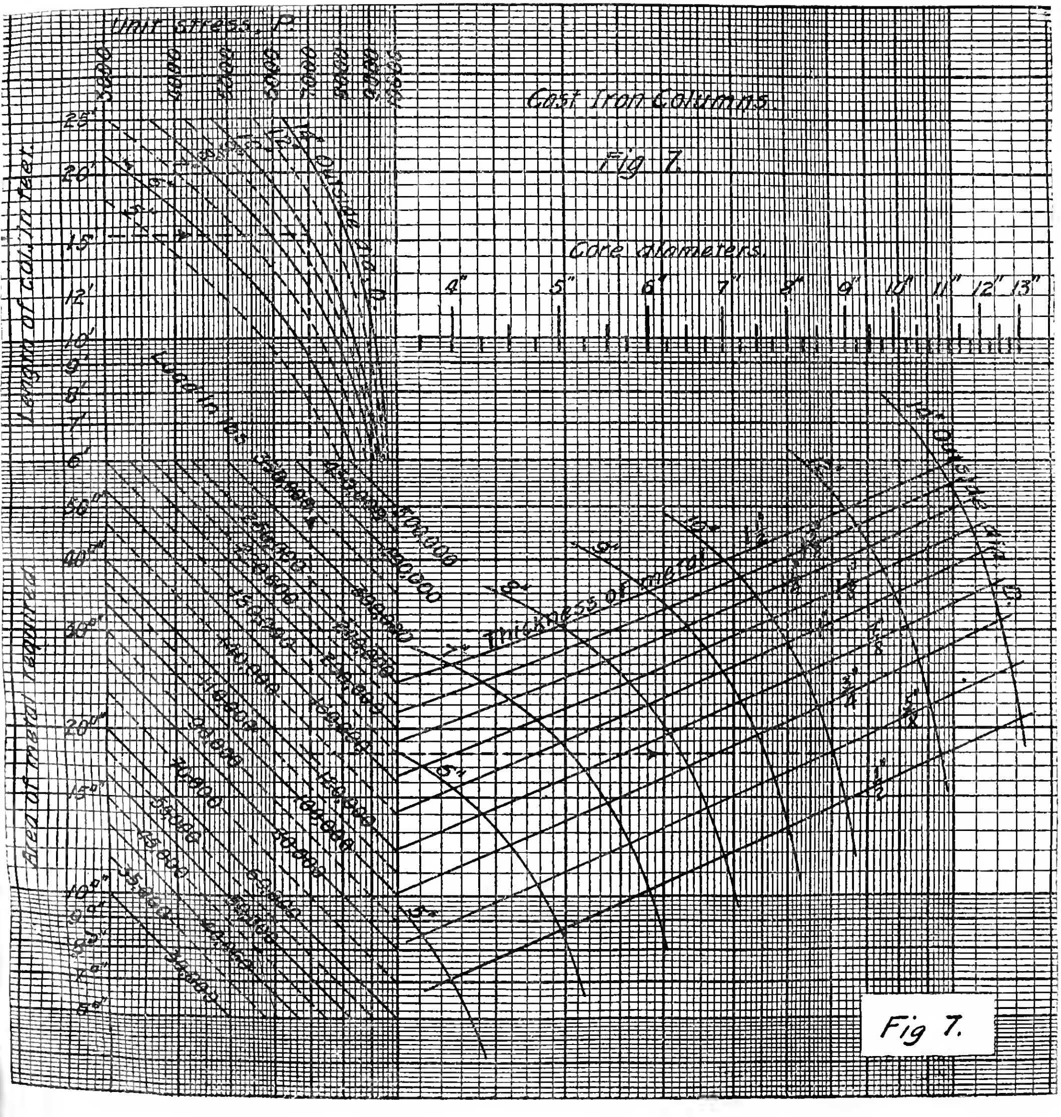

Cast Iron Columns.

Fig 7.

Fig 7.

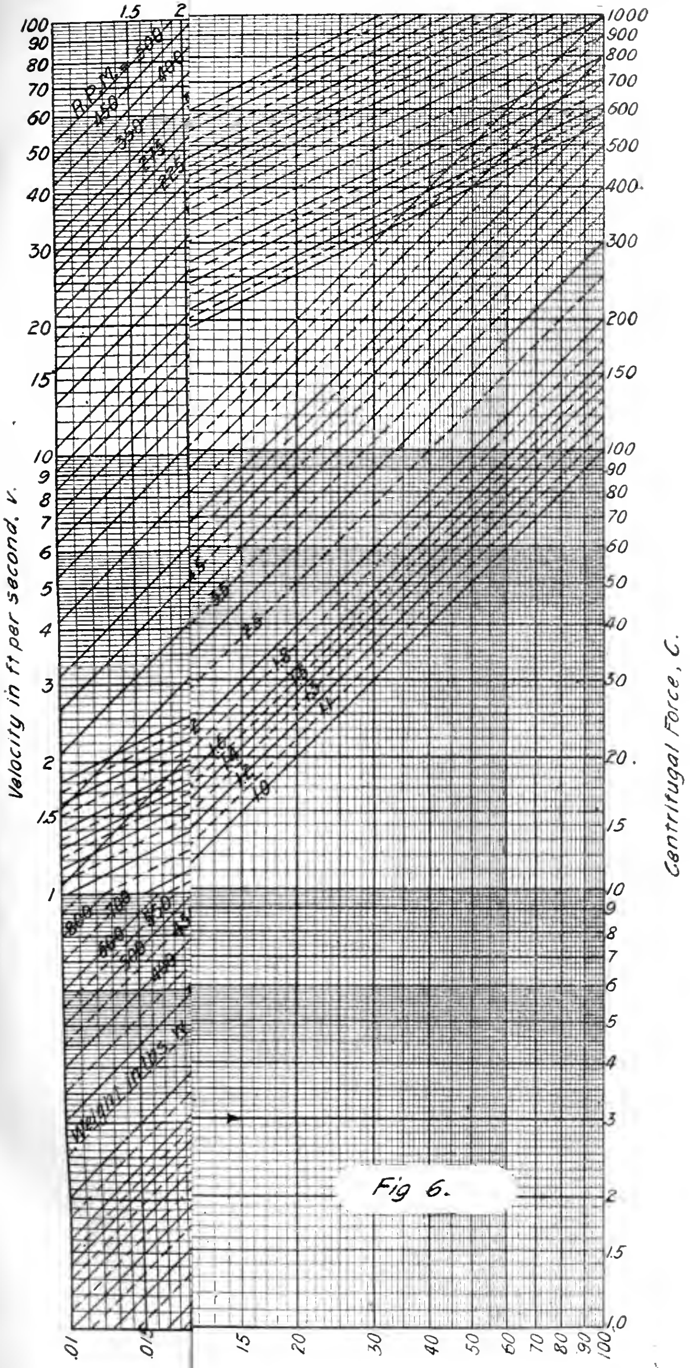

Fig 6.

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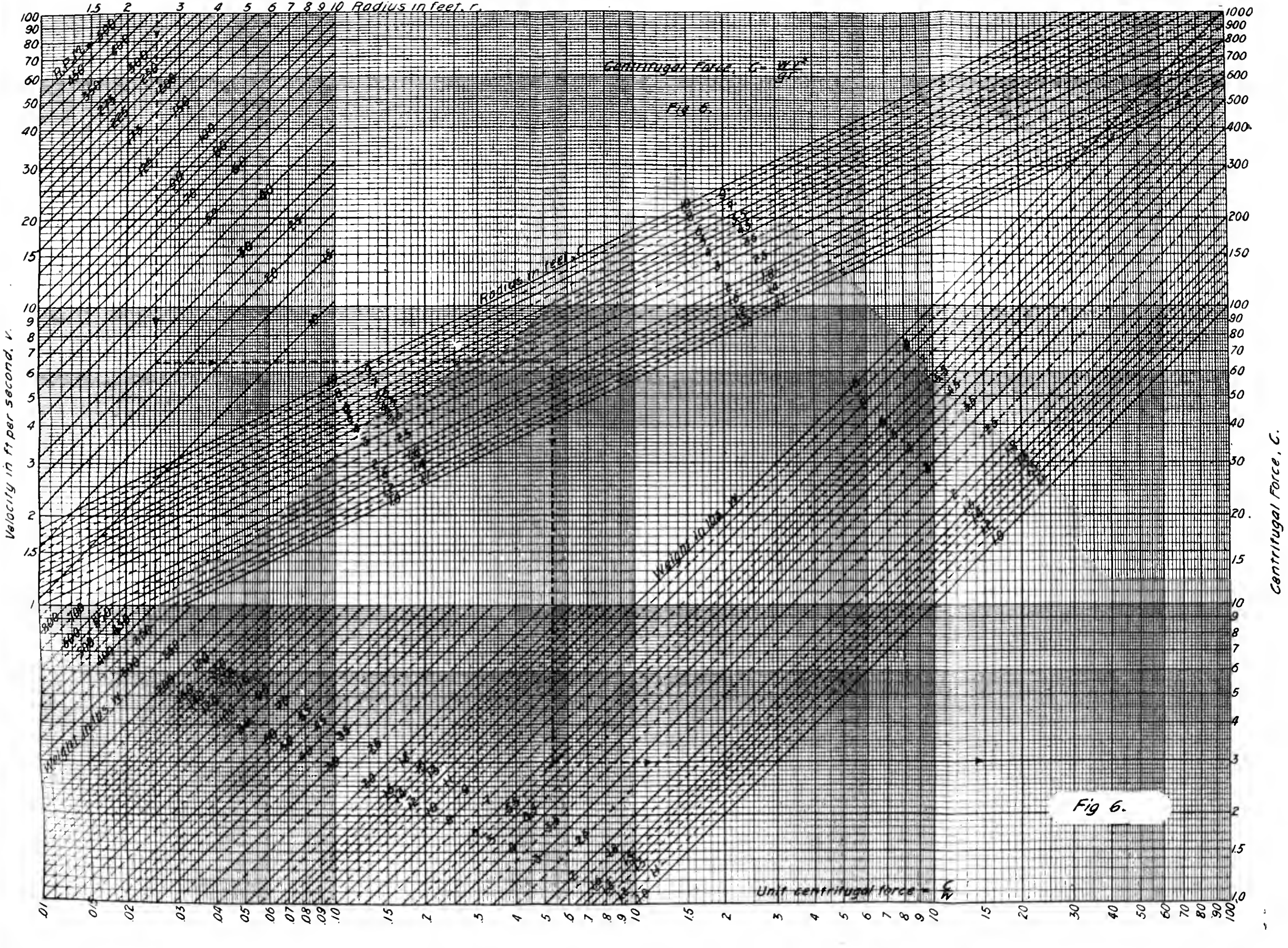
Fig 6.
Centrifugal Force, $C = \frac{Wv^2}{gr}$
Fig 6.
1.5 2 3 4 5 6 7 8 9 10 Radius in feet, r.
R.P.M.
Radius in feet, r.
Weight in lbs. W.
Weight in lbs. W.
Velocity in ft per second, V.
100 90 80 70 60 50 40 30 20 15 10 9 8 7 6 5 4 3 2 1.5 1
Centrifugal Force, C.
1000 900 800 700 600 500 400 300 200 150 100 90 80 70 60 50 40 30 20 15 10 9 8 7 6 5 4 3 2 1.5 1.0
Unit centrifugal force = C/W
.01 .015 .02 .03 .04 .05 .06 .07 .08 .09 .10 .15 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.5 2 3 4 5 6 7 8 9 10 15 20 30 40 50 60 70 80 90 100

multiplied by 10 or 100 respectively if the solution starts with r and r. p. m., while it will have to be divided by the same numbers if it starts with velocity directly.

CYLINDRICAL CAST IRON COLUMNS.

A diagram for the complete determination of the column necessary to carry any specified load is given in Fig. 7. The basis of this diagram is Gordon's formula,

$$P = \frac{80{,}000}{1 + \frac{(12L)^2}{800D^2}}, \text{ in which,}$$

P = the ultimate unit load for square ended columns,
L = length in feet,
D = outside diameter in inches,

80,000 being the ultimate unit compressive strength assumed for cast iron.

Since this formula contains but three variables, a simple diagram with one set of curves will suffice to plot all variations of unit-strength. This is done in the first set of curves of Fig. 7, with diameters from 5 to 14 inches, and plotted with lengths as ordinates and unit-strengths as abscissas. In these curves, however, a working strength of one-eighth of the ultimate was used, giving, therefore, the working unit-strength instead of the ultimate.

Having the unit-strength, the diagram may be extended another step so as to solve for the area of metal necessary to carry a given load by simply dividing the loads by the unit-strength, represented by the expression, $\text{Area} = \frac{\text{Load}}{P}$.

This relationship is plotted in the second set of lines on the diagram with the same P scale as the first set and with areas as ordinates.

It is possible now to still further extend the diagram so that the required area, combined with the knowledge of the diameter used at the start, will give the inside or core diameter. This result is obtained in the third set of lines, where each D curve is plotted by assuming the abscissas to represent the core areas of the columns and points on the curves located, by plotting the relationship expressed by Area of core = Area of D — Area of metal.

To enable the reading of core diameters, it becomes necessary then, that the points representing the areas of circles of various sizes be pointed off and marked on the axis of abscissas representing these core areas, when the diagram will become available for finding directly the outside and inside diameters of a column necessary to carry a given load.

To show a further possibility, another set of curves has been plotted crossing the last or second set of *D* curves. This gives the final dimension of design as the thickness of metal required instead of the core diameter, and is obtained by pointing off the intersections of the *D* curves with the abscissa representing a core area that would result with the given thickness of metal, and then connecting all points representing that thickness with a curve for that value of *t*.

The heavy dotted meander line indicates the solution for a column 15 ft.-6 in. long to carry a load of 125,000 lb. The diameter of column to be used may be limited in many ways, and often is determined by the limitations of the foundry in securing a sound casting. The solution as indicated assumes a diameter of 10 in., and shows a thickness of ⅝ in., of metal required. It is of course necessary that in any solution the same set of *D* curves be used in the last step as was used in the first step.

While this last diagram is plotted to solve for the strength of columns under a working stress of 10,000 lb. per sq. in., it could have been made universal in its application by the simple expedient of adding one step between the first and second as plotted, thus permitting the use of any stress desired. Thus, while the commonly used formula gives as results only the permissible load per square inch of metal, it is seen how easily additional steps may be added to make the completed diagram cover all applications of the original formula to problems commonly met in engineering work, and once the diagram has been constructed the solution of any problem is but the work of a few seconds.

In Figs. 8 and 9 is shown the application of diagrams to another type of solutions,—that of simple proportions as involved in the design of a line of machinery of a given type. The usual method in such a case is to build and perfect one size and then proportion others from this.

Two views of what is commonly known as a clam-shell bucket are shown in Fig. 8. With this class of machinery the rating is generally given in terms of cubic yards capacity, and it is evident that an equation for any linear dimension in terms of the rating will involve the cube root of the capacity of the given size, and this on ordinary paper would result in curves.

Assuming that the three-fourths yard size has been built experimentally and perfected, the problem becomes one of securing rational variations in proportions for other sizes. By referring to Fig. 9 the method used will be seen. Here the ordinate used is the rating in cubic yards, and the abscissas are the linear dimensions in inches. With all dimensions of the

tal locations of these
d ordinate.
of this paper, a line
dinate is involved to
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f which will be the
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the tangent of which
its intersections, the
the first one drawn
similar manner, the
nly a few are shown
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Weight Light. The
eight lines for small
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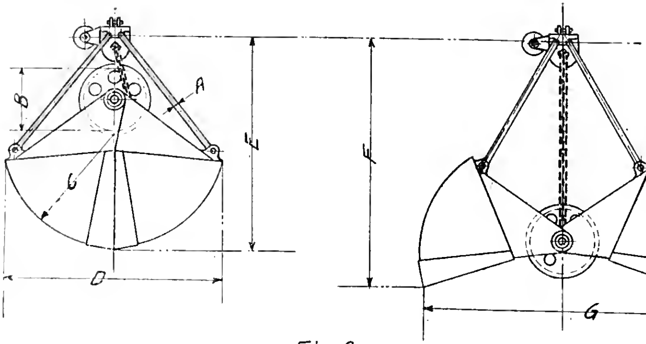

A
B
C
D
E
F
G

Fig 8.

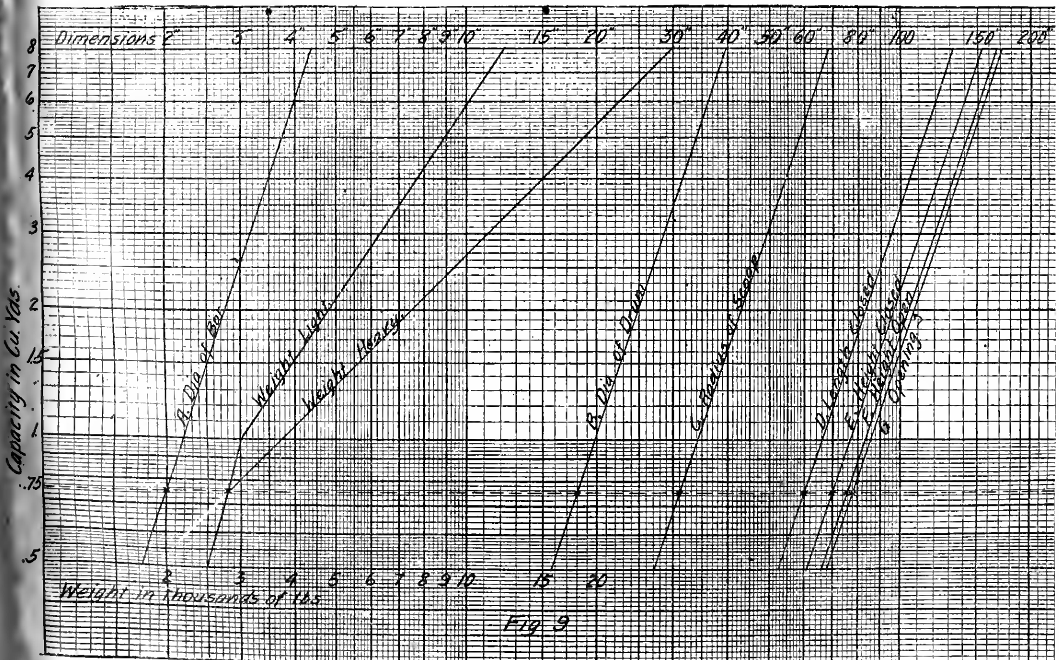

Dimensions 2" 3" 4" 5" 6" 7" 8" 9" 10" 15" 20" 30" 40" 50" 60" 80" 100 150" 200"
Capacity in Cu. Yds.
8
7
6
5
4
3
2
1.5
1.
.75
.5
A. Dia of Bar
Weight Light
Weight Heavy
B. Dia of Drum
C. Radius of Scoop
D. Length Closed
E. Height Closed
F. Height Open
G. Opening
2 3 4 5 6 7 8 9 10 15 20
Weight in thousands of lbs

Fig 9

three-fourths yard size known, the horizontal locations of these points are plotted on the three-fourths yard ordinate.

Now, as explained at the beginning of this paper, a line representing an expression in which the ordinate is involved to any degree as the one-third, or cube root, will make an angle with the axis of ordinates, the tangent of which will be the exponent of the power or one-third. Take any dimension then, as *E*, the height closed, and draw a line through the plotted point, making an angle with the vertical, the tangent of which is one-third, and this line will then give, by its intersections, the lengths of all other sizes. Lines parallel to the first one drawn through the other points plotted, give, in a similar manner, the dimensions of other parts, and although only a few are shown here, it is evident that the principle can be extended indefinitely to cover practically all linear dimensions.

The weight of such a machine should rationally vary about as the capacity. For the heaviest materials to be handled this proves true, and the 45° line marked *Weight Heavy* would indicate the variations on this basis. For lighter materials it is possible to reduce the weight per unit of capacity in the larger sizes, and this is shown by the line marked *Weight Light*. The reason for the break in direction of the weight lines for small sizes is that when a certain size is reached the minimum sections are used, and below this the reduction in weight is small.

DISCUSSION.

President Alvord: I am sure we have all listened with great interest to Mr. Dodge's paper. It seems to me that the tremendous advantage of diagrammatic representation of formulae lies particularly in this—that much of the data for computation are subject to variation in judgment. If one then proceeds to a numerical demonstration, he fatigues himself, he confuses his mind with detail and obscures, often, the point that he is trying to make clear—the effect of variation on the data with which he began. This is particularly true in hydraulics, where data are usually inexact. The benefits of a diagram in solving any hydraulic problem lie in the fact that one may see at a glance the effect of any variation in his original data, and may vary his premise without any mental fatigue and thereby give himself the opportunity of concentrating his thought entirely on the general relations of his answer. This is one reason why I have personally, for many years past, preferred to use diagrams to computations. I think, of course, there is some danger involved—that of losing technique—but the busier a man gets to be and the more important he finds his work, the more he wishes to concentrate his attention upon the final result—its relation to the factors with which he started—rather than any intermediate drudgery.

B. E. Winslow, M. W. S. E.—I have found it advantageous to use logarithmic scales of different sizes. With a number of scales of this kind it is often possible to make the diagram gain very much in clearness.

It is of importance to construct all diagrams directly from the given formula, and to bring the formula either into the form of

$$a = \frac{y}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{or } b = xy \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

when constructing the diagram.

The characters a and b are here arbitrary constants and x and y are co-ordinates in a cartesian system.

Equation (1) is that for a family of straight lines lying in one plane and meeting at the point o, and (2) is an equation for a family of equilateral hyperbolas lying in one plane and referred to their asymptotes.

Taking the logarithm of the above two expressions there results:

$$\log a = \log y - \log x \quad \ldots\ldots\ldots\ldots (3)$$

$$\text{and } \log b = \log x + \log y \quad \ldots\ldots\ldots\ldots (4)$$

both of which equations represent a family of straight lines lying in one plane when $\log x$ and $\log y$ are co-ordinates in a cartesian system.

If now (1) has the form $a = \frac{y^2}{x}$, we have by taking the logarithms of the expression

$$\log a = 2 \log y - \log x.$$

By using a scale for $\log y$ equal to one-half that used for $\log x$, it will be possible to retain the 45° inclination of the diagonal lines.

All of the above equations contain two variables and are solved by a family of lines lying in one plane, where the two co-ordinates represent the two variables. The great majority of diagrams come under this form.

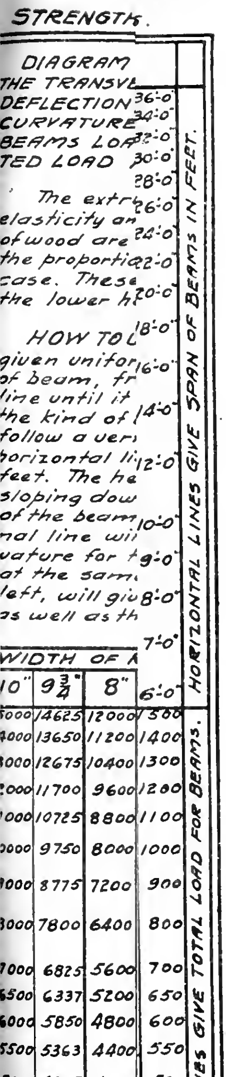
The same general principles can also be made to apply to expressions containing three or more variables.

Thus, taking the logarithm of the expression $b = xyz$, we have:

$$\log b = \log x + \log y + \log z$$

which equation represents a family of straight lines in various planes in space, where $\log x$, $\log y$ and $\log z$ are the three co-ordinates in space. Such a family of lines can also, with great ease, be shown on a diagram by following the rules governing ordinary projection drawing.

In a diagram of this kind the lines are all clearly given by a horizontal and a vertical projection. Many of the diagrams given in my book on diagrams and tables for calculating the strength of wood, steel and cast iron beams and columns, published by the



10"	9¾"	8"	
5000	14625	12000	500
4000	13650	11200	1400
3000	12675	10400	1300
2000	11700	9600	1200
1000	10725	8800	1100
0000	9750	8000	1000
9000	8775	7200	900
8000	7800	6400	800
7000	6825	5600	700
6500	6337	5200	650
6000	5850	4800	600
5500	5363	4400	550
5000	4875	4000	500
4500	4387	3600	450
4000	3900	3200	400
3500	3413	2800	350
3000	2925	2400	300
10"	9¾"	8"	WIDTH 1"

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STRENGTH AND DEFLECTION OF UNIFORMLY LOADED RECTANGULAR WOODEN BEAMS.

DIAGRAM GIVING THE SHEARING STRENGTH, THE TRANSVERSE BENDING STRENGTH, THE DEFLECTION, AND THE MINIMUM RADIUS OF CURVATURE FOR RECTANGULAR WOODEN BEAMS LOADED WITH A UNIFORMLY DISTRIBUTED LOAD AND SUPPORTED AT BOTH ENDS.

The extreme fiber stress, the modulus of elasticity and the shearing stress for each kind of wood are taken proportional to each other, the proportion remaining constant in each case. These stresses are taken as shown on the lower half of the diagram.

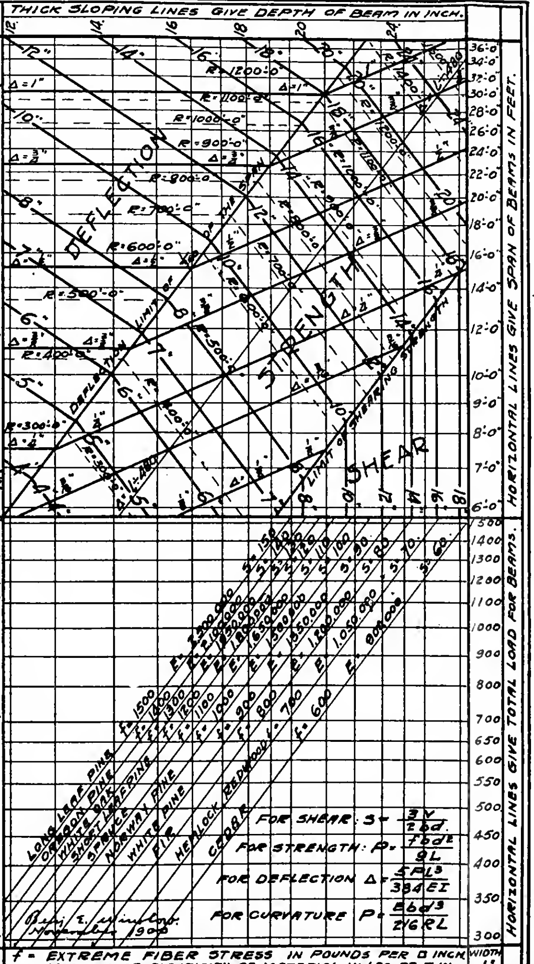
HOW TO USE THE DIAGRAM: Find the given uniform load under any assumed width of beam, from this point trace a horizontal line until it intersects the diagonal line giving the kind of wood desired. From this intersection follow a vertical line until it intersects the horizontal line giving the span of the beam in feet. The heavy diagonal line at this point, sloping downward to the right, will give the depth of the beam required, while the dotted diagonal line will give the minimum radius of curvature for the case in hand. The diagonal lines at the same point, sloping downward to the left, will give the actual deflection of the beam as well as the deflection in terms of the span.

WIDTH OF RECTANGULAR WOODEN BEAM IN INCHES

TOTAL DISTRIBUTED LOADS IN LBS. FOR BEAMS OF VARIOUS WIDTHS

10"	9¾"	8"	7¾"	6"	5¾"	4"	3¾"	3"	2¾"	2"	1¾"
15000	14625	12000	11625	9000	8625	6000	5625	4500	4125	3000	2625
14000	13650	11200	10850	8400	8050	5600	5250	4200	3850	2800	2450
13000	12675	10400	10175	7800	7475	5200.	4875	3900	3575	2600	2275
12000	11700	9600	9300	7200	6900	4800	4500	3600	3300	2400	2100.
11000	10725	8800	8525	6600	6325	4400	4125	3300	3025	2200	1925
10000	9750	8000	7750	6000	5750	4000	3750	3000	3750	2000	1750
9000	8775	7200	6975.	5400	5175	3600	3375	2700	2475	1800	1575
8000	7800	6400	6200	4800	4600	3200	3000	2400	2200	1600	1400
7000	6825	5600	5425	4200	4025	2800	2625	2100	1925	1400	1225
6500	6337	5200	5037	3900	3737	2600	2437	1950	1787	1300	1137
6000	5850	4800	4650	3600	3450	2400	2250	1800	1650	1200	1050
5500	5363	4400	4263	3300	3163	2200	2063	1650	1512	1100	963
5000	4875	4000	3875	3000	2875	2000	1875	1500	1375	1000	875
4500	4387	3600	3487	2700	2587	1800	1687	1350	1237	900	783
4000	3900	3200	3100	2400	2300	1600	1500	1200	1100	800	700
3500	3413	2800	2713	2100	2013	1400	1313	1050	963.	700	613
3000	2925.	2400	2325	1800	1725	1200	1125	900	825	600	525
10"	9¾"	8"	7¾"	6"	5¾"	4"	3¾"	3"	2¾"	2"	1¾"

WIDTH OF RECTANGULAR WOODEN BEAM IN INCHES.



FOR SHEAR: $S = \frac{3V}{2bd}$.

FOR STRENGTH: $P = \frac{fbd^2}{9L}$

FOR DEFLECTION $\Delta = \frac{5PL^3}{384EI}$

FOR CURVATURE $P = \frac{Ebd^3}{216RL}$

f = EXTREME FIBER STRESS IN POUNDS PER □ INCH
E = MODULUS OF ELASTICITY OF MATERIAL IN LBS. PR □ IN.
S = MAXIMUM SHEARING INTENSITY IN LBS. PR. □" AT NEUTRAL AXIS.

Fig. 10.
Winslow's Diagrams.

Engineering News Publishing Co. in 1900, are of this form. In these diagrams the upper portion is the vertical projection of the lines, and the lower portion is the horizontal projection of the lines. As space contains an infinite number of planes, it is possible to show on such a diagram very much more than can be shown on a diagram in one plane only. Diagrams of this kind are now being used more and more.

The same principles can be applied to expressions containing four or more variables, by simply continuing the projection on similar additional volumes or planes in space. An illustration of this is found on Plate XVIII of my book, mentioned above. For such cases there will simply be an additional projection for each additional variable in the formula, and each individual projection or diagram is followed up and brought into the form of (3) or (4).

When so many variables are involved it is better to use the slide rule. A slide rule can take care of any number of variables by simply adding a scale for each additional variable.

Moreover, it is possible, in my opinion, to construct diagrams that are even more practical than the slide rule. Such a diagram is shown on Fig. 10, and gives the shearing strength, the transverse bending strength, the deflection and radius of curvature for uniformly loaded rectangular wooden beams. In Fig. 10, the lower part of the diagram or the horizontal projection of the lines in space, is arranged to be common for *all* lines. On the upper part of the diagram one family of lines results from the shearing strength, another from the transverse bending strength, another from the deflection of the beams, and still another from the radius of curvature of the beams. Solving any case, we arrive at a point in the upper portion of the diagram, and from the position of this point it is possible to tell at a glance all about this special case. A diagram that is built up in this manner gives the desired informaton better and more quickly than a slide rule. In this connection it is interesting to notice, that the lines giving the deflection in terms of the span, are parallel with the lines giving the limit of shearing strength of the beams. If a deflection of $\frac{1}{720}$ of the span is assumed, these lines will become identical, showing that there is an intimate relationship between the shearing strength and the deflection of beams, not yet well understood, and not yet mentioned in the engineering press.

A similarly built up diagram for figuring the strength of reinforced concrete slabs is given in Fig. 11, but not so extensive as in Fig. 10. In this diagram the portion giving the horizontal projection and the portion giving the vertical projection are drawn one over the other. This is a dangerous thing to do, because it is possible to go through the diagram the wrong way, in which case wrong results are obtained. For this reason it is better to keep the vertical and horizontal projections separate.

Going through this diagram in solving any problem, one can see at a glance, 1st, the stress in the steel; 2nd, the stress in the

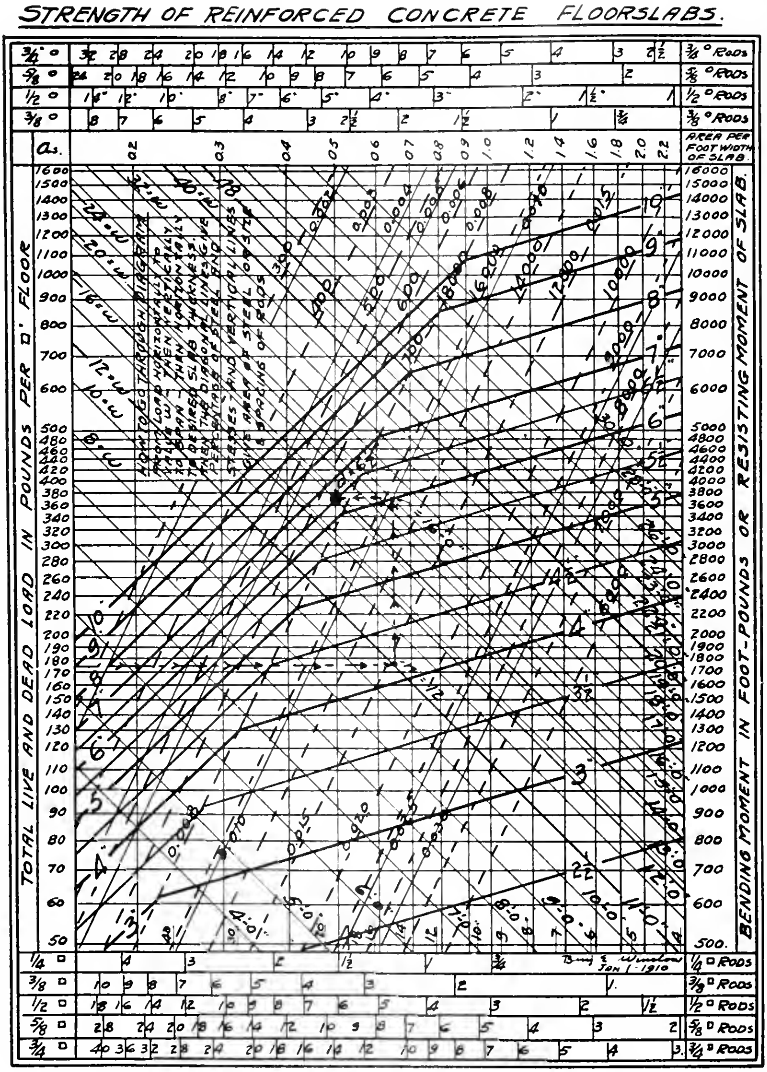


FIG 11.

Winslow's Diagrams.

concrete; 3rd, the percentage of the steel, and the spacing of rods for any size of rod.

he same ground as
r arrow on Scale 8,
ow on Scale 8 any
in Fig. 13, which
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the upper arrow
Another slide rule
of rectangular re-
raight line theory,

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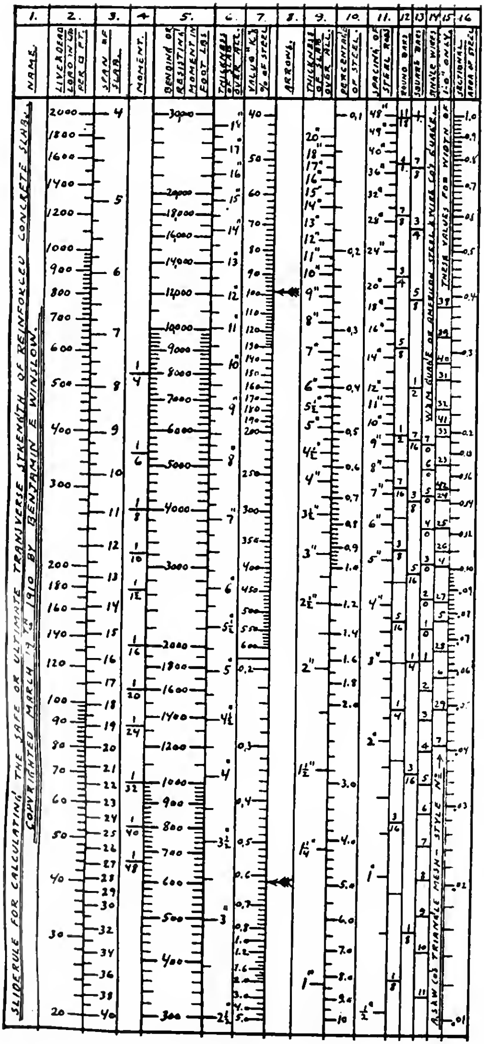
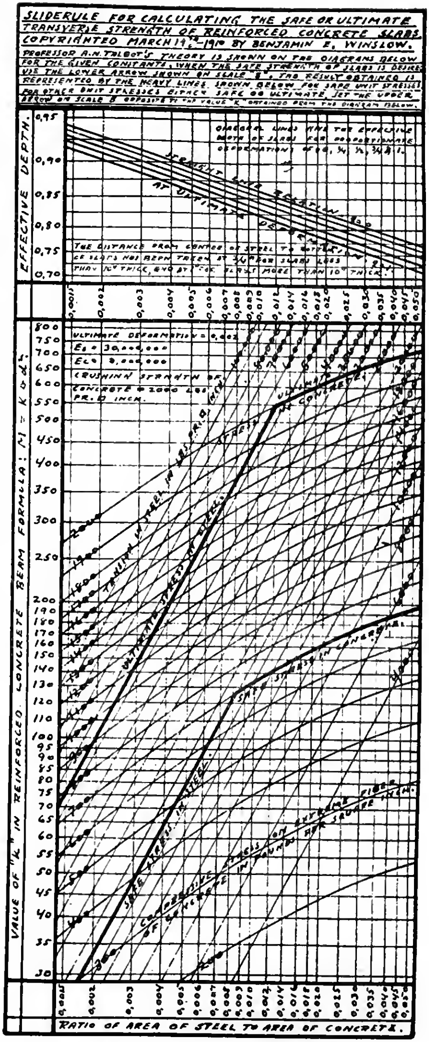

1. NAME.
2. LIVE LOAD IN LBS PER □ FT.
3. SPAN OF SLAB.
4. MOMENT.
5. BENDING OR RESISTING MOMENT IN FOOT LBS
6. THICKNESS OVER ALL.
7. VALUE "K". % OF STEEL
8. ARROWS.
9. THICKNESS OF SLAB OVER ALL.
10. PERCENTAGE OF STEEL.
11. SPACING OF STEEL RODS
12. ROUND BARS
13. SQUARE BARS
14. TRIANGLE WIRES
15. 1'-0" ONLY
16. SECTIONAL AREA OF STEEL
SLIDERULE FOR CALCULATING THE SAFE OR ULTIMATE TRANSVERSE STRENGTH OF REINFORCED CONCRETE SLABS.
COPYRIGHTED MARCH 19TH 1910 BY BENJAMIN E. WINSLOW.
W. & M. GUAGE OR AMERICAN STEEL & WIRE CO'S GUAGE.
THESE VALUES FOR WIDTH OF 1'-0" ONLY
A.S.&W. CO'S TRIANGLE MESH - STYLE No.

Fig. 12.

Winslow's Diagrams.


SLIDERULE FOR CALCULATING THE SAFE OR ULTIMATE TRANSVERSE STRENGTH OF REINFORCED CONCRETE SLABS. COPYRIGHTED MARCH 19TH 1910 BY BENJAMIN E. WINSLOW.

PROFESSOR A. N. TALBOT'S THEORY IS SHOWN ON THE DIAGRAMS BELOW FOR THE GIVEN CONSTANTS. WHEN THE SAFE STRENGTH OF SLABS IS DESIRED USE THE LOWER ARROW SHOWN ON SCALE "8". THE RESULT OBTAINED IS REPRESENTED BY THE HEAVY LINES SHOWN BELOW. FOR SAFE UNIT STRESSES FOR OTHER UNIT STRESSES EITHER SAFE OR ULTIMATE, SET THE UPPER ARROW ON SCALE 8 OPPOSITE TO THE VALUE "K" OBTAINED FROM THE DIAGRAM BELOW.

THE DISTANCE FROM CENTRE OF STEEL TO BOTTOM OF SLABS HAS BEEN TAKEN AT 3/4" FOR SLABS LESS THAN 10" THICK, AND AT 1" FOR SLABS MORE THAN 10" THICK.

ULTIMATE DEFORMATION = 0.002

E_s = 30,000,000

E_c = 2,000,000

CRUSHING STRENGTH OF CONCRETE = 2000 LBS PR. □ INCH.

EFFECTIVE DEPTH.
0,95
0,90
0,85
0,80
0,75
0,70
OBLIQUE LINES ARE THE EFFECTIVE DEPTH OF SLABS FOR PROPORTIONATE DEFORMATIONS OF 0, 1/4, 1/2, 3/4 & 1.
STRAIGHT LINE RELATION 2000
AT ULTIMATE DEFORMATION
VALUE OF "K" IN REINFORCED CONCRETE BEAM FORMULA: M = K b d².
ULTIMATE STRESS IN STEEL
TENSION IN STEEL IN LBS. PR. □ IN.
ULTIMATE STRESS IN CONCRETE
SAFE STRESS IN STEEL
SAFE STRESS IN CONCRETE
COMPRESSIVE STRESS ON EXTREME FIBRE OF CONCRETE IN POUNDS PER SQUARE INCH.
RATIO OF AREA OF STEEL TO AREA OF CONCRETE.

Fig. 13.

The slide rule, shown in Fig. 12, covers the same ground as Fig. 11, when used in connection with the lower arrow on Scale 8. When used in connection with the upper arrow on Scale 8 any problem can be solved for any stress given in Fig. 13, which illustrates Prof. Talbot's theory for a given mixture of concrete, or for any stress and any theory by sliding the upper arrow opposite to the proper value of K, on Scale 7. Another slide rule has been devised for calculating the strength of rectangular reinforced concrete girders by the common straight line theory, for a given mixture of concrete.

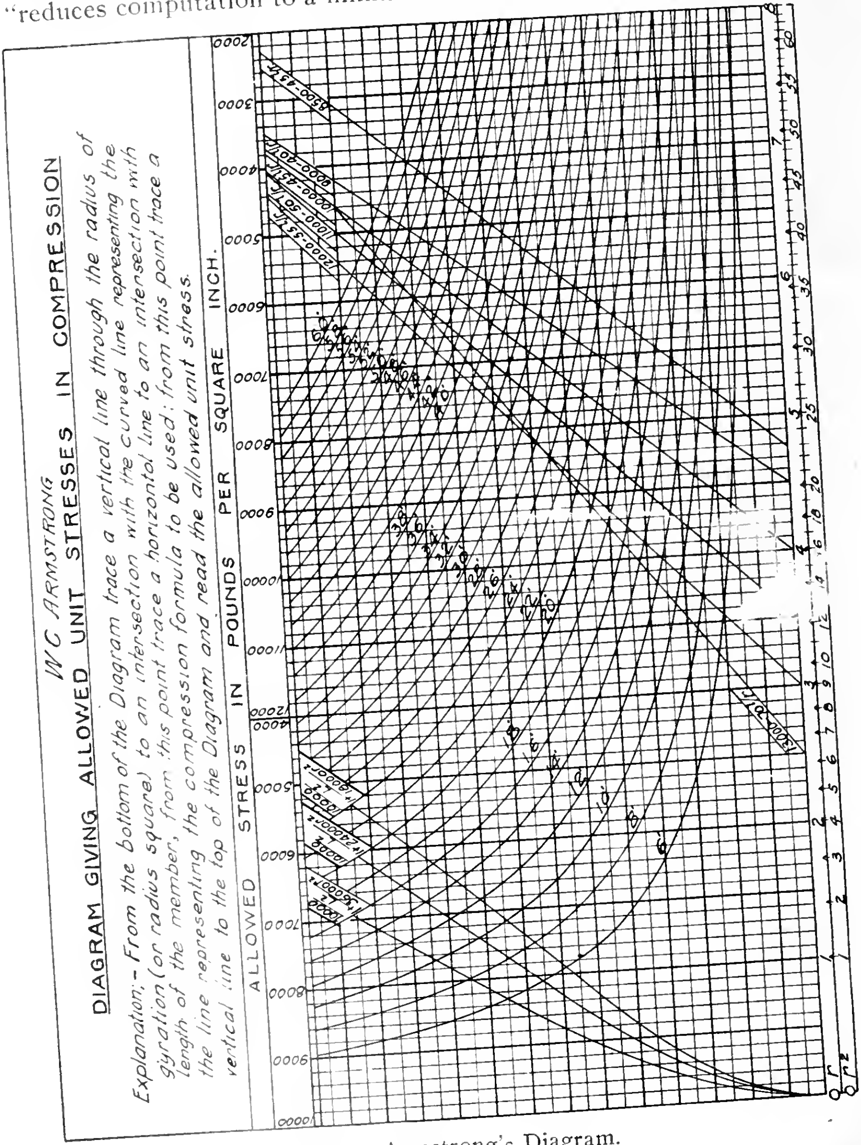
The above shows that a given mathematical expression can be solved, either by diagram or by slide rule. Sometimes the diagrammatic method is the better, but as a rule slide rules specially constructed for the purpose, are better and easier to use than diagrams. The work is done mechanically and the liability for making mistakes is reduced to a minimum.

W. C. Armstrong, M. W. S. E.—I think we have all been very much interested in the paper by Mr. Dodge, presented this evening. There are a great many problems that I think can be much more quickly solved by means of diagrams than they can in any other way, even by the slide rule. Take as an illustration the one Mr. Winslow referred to—diagrams for reinforced concrete construction. There are a great many such cases where the formula involves a number of variables, one or more of which must be assumed and the others calculated, and the solution is a "cut and try" method. In cases of that kind diagrams are a great advantage. The use of logarithmic cross-section paper I am sure is a great advantage over the older system of using the ordinary co-ordinate paper.

This might be illustrated by the following diagram, Fig. 14, which I worked out a number of years ago, for computing the allowable unit stresses on steel compression members. The values of r (radius of gyration) are laid off along the axis of abscissas. On a logarithmic scale immediately under this axis is laid off values of r^2, so that r and r^2 have the same measurement on the diagram. The series of curved lines which are approximately concentric, represent the length of the member. Curved lines representing Gordon formulas are shown at the left, while straight-line formulas are shown by the diagonal lines at the right. The method of using the diagram is explained in the heading.

A good deal of labor was involved in constructing this diagram, as a large number of points had to be established for each curve. The use of logarithmic cross-section paper would have eliminated a large amount of this labor, as all lines would then have been straight. After the diagram is constructed I do not know that there is any advantage in one over the other. Logarithmic cross-section paper had not come into use at the time this was worked out

A. W. Moseley, M. W. S. E.—The claim has been made by some one interested in the sale of logarithmic paper that it "reduces computation to a minimum and insures absolutely accurate results." This is a strong claim and cannot be substantiated. The logarithmic scale has advantages when used in connection



W C ARMSTRONG

DIAGRAM GIVING ALLOWED UNIT STRESSES IN COMPRESSION

Explanation;- From the bottom of the Diagram trace a vertical line through the radius of gyration (or radius square) to an intersection with the curved line representing the length of the member, from this point trace a horizontal line to an intersection with the line representing the compression formula to be used; from this point trace a vertical line to the top of the Diagram and read the allowed unit stress.

Fig.14. Armstrong's Diagram.

with certain kinds of computations; but in general it is subject to the limitations met in all plotting.

Three or four questions have arisen in my mind with regard to the disadvantage of logarithmic paper.

First: It gives a distorted picture. One of the important things brought out by a plot in the ordinary scales is the graphical impression of the changes of one of the variables with regard to the changes in the other variable.

Second: With the ordinary logarithmic paper, the scale for plotting is fixed, hence the usefulness of the paper is limited. That is, it is not possible to choose the scale at will.

Third: The paper is limited as to range. Take, for instance, the relation $x = z^n$, and let the exponent be such that there is a large range in x for a limited corresponding range in z. Such a relation could not, of course, be put upon a single sheet of the paper.

Fourth: It is only one particular form of relation that becomes a straight line on the logarithmic paper, all others being curved.

Another thing that occurs to me is the question of negative values. These could not be plotted. However, such cases do not often occur in ordinary problems of design. Such plots as I have made upon logarithmic paper have been of a kind that were peculiarly suited to the method, and there is no doubt that the logarithmic scale has great value and advantage in certain cases.

I mention these things largely in the nature of questions, and hope that some of them may be answered this evening. No doubt some of those present have met these difficulties and found solutions for them.

E. C. DeWolfe, M. W. S. E.—Mr. Dodge has given me credit in this paper as having been the "oldest inhabitant" in the logarithmic paper line. I want to say that this is hardly justified, because I obtained it from somebody else. I saw it used long before I undertook to use it myself.

In regard to the matter of variable scales, Prof. Moseley's question is unanswerable, except to say that stock paper will give him no freedom from that limitation. In my work in diagrams, after using logarithmic paper for sketching out originally and doing the scheming which is always necessary, I have then done my ruling with scales of my own. In handling a second power quantity, as Mr. Winslow says, the thing to do is to use a half scale, so that the lines will still remain at 45°, or with an angle whose tangent is 1, instead of an angle whose tangent is 2. That takes care of the matter of the nth power; it is merely a matter of the selection of scales.

The great advantage of the logarithmic paper is that the percentage of error or accuracy is constant over the area. As Mr. Dodge has stated, there is no loss of accuracy as we approach the origin. The only variation from this is that as we approach 10 or 100 on the logarithmic paper, the divisions come closer together and some of them have to be omitted. We are all familiar with that condition on the slide rule.

In regard to the diagram proposition in general, President Alvord's statement that there are a great many differences of opinion among good authorities as to the proper formulae to use in different cases, is about right. The thing to do is to get the formula or expression which is right, make the diagram accurately, and forget the disagreement among competent authorities.

One great value of a diagram in general is its assistance in getting quick results in problems which must involve the cut and try method. In the beam diagram, shown us by Mr. Winslow, there is the matter of allowance of relative breadth and depth, and while I do not know what his difficulties were in contriving it, I should say that his breadth and depth should come at the same side of the diagram, so that in sloping in he could come to a point where he could pick a breadth and depth to conform to his condition. These things which must be juggled together, must be brought together on the diagram.

Another advantage of the diagram is that we can work from *any* unknown variable to the solution without any transposition of formulae. We can start in the middle and work both ways in a good many cases, and save much time that would be wasted in working out formulae.

The question as between the ordinary slide rule and the diagram and the special slide rule is, as Mr. Winslow has indicated, a matter of expediency in a given case. The diagram and the special slide rule are nearly on an equal footing up to expressions which involve four or five variables. Beyond that the possibility of error in reading from point to point, following the meander line through a diagram, introduces opportunity for a multiplication of error on the way, while the special slide rule eliminates that. But as compared to the use of the ordinary slide rule for a great many things, the diagram is, to my mind, far preferable.

The construction of diagrams in my experience has been mainly one of ingenuity—to get the several variables so arranged that the diagram will be simple, that there will be not too many sections to it, and that there will not be too many sets of crossing lines in one section. We have to look out for clearness in reading; we have to look out to see that in following through any possible problem we are not going to call for unreasonably great area of diagram in order to include the desired range for the variables.

Often a reversal of slope for the lines of a certain variable will help. In such a case, as shown by Fig. 3 in the paper, where a line runs upward to the right, with the abscissas increasing toward the right, the slope of the line can be reversed by letting the abscissas read in the opposite direction. That enables us sometimes to get two sets of lines crossing at right angles on the same diagram, keeping within close reasonable ranges of area for wide ranges of values. It also enables a very quick reading from one margin in to one set of diagonal lines, thence to the other diagonal lines, and out to the margin of the diagram to read the result.

Of course, the diagram eliminates all necessity for interpolation of values, as is necessary with the most complete set of tables. A table is of no value for more than three variables, except that where one of four variables will have only three or four values, a table may be arranged in sets of three or four columns to correspond to the values picked out. The diagram will eliminate that almost completely. One can interpolate very readily in following the lines, just as he can on a slide rule.

Mr. Dodge has spoken of my following diagonal lines sometimes instead of turning at right angles. That has been done mainly to avoid making a complete divisional section of the diagram and is a very useful expedient where the variable involved in that diagonal direction has only a few possible values or a small range of value; as, for instance, in a diagram which might be constructed for the simple proposition of capacities of tanks, whether round or rectangular bases, or circular or elliptical. Square or rectangular base involves simply the product of the dimensions of the base; circular or elliptical involves the diameter squared or the product of the axes, multiplied in either case by 0.7854. A diagram can easily be constructed wherein the entrance method for square or rectangular base applies also for circular and elliptical forms; then for the latter forms the correction 0.7854 is made by following a short diagonal to raise or lower the point at which the next section of the diagram is entered. Similarly, for shafting, where the service must be considered, whether for head shafting, line shafting, or counter shafting. A system of short diagonal lines will elevate or depress the position of entering the table, according to the service and the corresponding divisor in the formula. With only a very few such values, this method is more simple than to make another section to the diagram.

Another case is that of the pressure between paper friction wheels—a pressure which might vary from 100 to 200 pounds, and for which four or five values are sufficient in the diagram.

Most of my work in diagrams has been in the solution of very simple problems which came within my work for frequent repetition, and while the special slide rule would certainly be, I believe, better than a diagram, diagrams were easily constructed and I made a great many of them—fifty or more, probably. Some of them were sent to the technical press and published; and if anybody here wants to know an easy way at the present time to make some money as a contributor to the technical press, he can work up some good diagrams; they will be accepted with avidity.

Mr. Alvord: It has always seemed to me that there was quite a field for the production of a good diagrammatic notebook. We see a great many diagrams published over and over again in various forms, differing very little, some not quite so good as their predecessors, and there certainly is room for some one who wants to go down to fame and posterity to compile a good, thorough, up-to-date book of diagrams, well worked out for all of the standard lines of work.

A. N. Talbot, M. W. S. E.—This subject of graphical diagrams is one of general interest, and Mr. Dodge has done a service to the members of this Society, particularly to the younger members, in writing this paper. Such diagrams have a wide range of applicability.

I think my attention was first called to the advantages of diagrams for making calculations by Mr. A. M. Wellington, who published his book of diagrams on earthwork quantities about thirty years ago. In hydraulic calculations diagrams are very convenient, and there are many complicated formulas—seemingly complicated at least—which, when reduced to a diagram, become quite simplified. Take Kutter's formula as an example—a formula about which we have all had a vague understanding. If that is plotted to logarithmic scale for particular values of n, the relations between the velocity and the slope will be very nearly a straight line—so nearly so that by calculating three or four values for any given diameter or hydraulic radius of section the line may be readily plotted on the diagram.

The feature of accuracy has been referred to. It comes to my mind that sometimes one may get results more nearly accurate in diagrams by changing the direction of the co-ordinate axes. Instead of making the axes at right angles to each other, it is possible to incline them towards each other so that when the lines representing the functions are in the same general direction the angle of intersection with the two co-ordinates may give much closer results. As an instance of that I will cite a little diagram which was printed in the Technograph back in 1892 or 1893 for the flow through sewers, using Kutter's formula. These axes were inclined toward each other at an angle which gave much better intersections than would be obtained with rectangular axes.

I am glad to know that dealers are prepared to furnish logarithmic paper; it is certainly very useful; but I wonder why they do not supply paper of larger scale. By good fortune I was furnished, many years ago, with some excellent logarithmic paper by Mr. John R. Freeman, the hydraulic engineer, who had prepared two plates for his own use. The plates were, as I recall them, 20 inches square; one plate ran from 1 to 10, and the other plate from 1 to 100 and were very accurately graduated. I hope that there will be enough interest in the matter some time that this paper may be put on the market, or that other plates of the same size and scale may be available.

In regard to whether logarithmic paper gives natural results or not, I think that depends somewhat on the way we look at it. Before I used logarithmic paper to a considerable extent my feeling was a good deal like that of Professor Moseley, that the scale was unnatural and distorted; but in the representation of certain functions I have come to believe that the logarithmic paper gives a natural scale. To me it gives a more intelligible representation of a function than is given by the ordinary scale, when dealing, I mean, with the relation of quantities, with the effect of one variable upon another. Also, the relative error is much the same for the large values as for the smaller ones, even though the scale of the drawing seems to be so much different. The scale is not so limited, either, as it would seem to be, since by bringing the point from the top of the paper down to the bottom a line may be continued on a new scale.

One use of diagrams, whether on the ordinary natural coordinate scale or on logarithmic paper, it seems to me is very advantageous to the engineer—a use not mentioned by Mr. Dodge in his paper—the plotting of data, results of observations, or experiments, from which the determination of an equation or function to represent a law of the action involved. For this purpose the logarithmic paper is especially advantageous. I recall using logarithmic paper this year for the determination of the law of flow through locomotive water columns, valve losses and other losses; also, the plotting of losses due to friction through pipe. In making calculations to find what form of equation should be used to express the relation of train resistance to speed of train and weight of car load, I found that by plotting this on logarithmic paper a relation became at once so apparent that it was very easily expressed algebraically.

Mr. Dodge: Mr. Winslow's discussion made a little plainer the point that I tried to bring out of the effect of a constant *G* in the diagram of the equation for centrifugal force. That has simply the effect of doing what he mentions on his diagrams, sliding one set of lines on the other. If that had been some such expression that *G* might have had one or two values, it would have been taken care of in just the way that he mentioned.

Mr. DeWolfe: That sliding plane matter is just what I was trying to get at in speaking of my diagonal lines. It is the same thing, whether we slide planes together to get different positions for entering a diagram or for passing from one part to another, or whether we follow a diagonal to effect the same change.

John B. Peddle, Rose Polytechnic Institute, (by letter). As Mr. Dodge observes, the English speaking engineers seem to be much behind those of continental Europe in the use of the calculating chart. In France particularly there seems to be a widely diffused knowledge of the subject among the engineering fraternity, and many excellent charts have been published there for the solution of formulae.

In view of this fact, it seems a little strange that more information on the subject has not penetrated this country and become a part of our common knowledge, since our engineers are generally quick to appreciate and use time and labor-saving devices.

Mr. Dodge will have rendered a valuable service if his paper is the means of stimulating an interest in this useful study, and it is to be hoped that the lucid manner in which he has handled his theme may help to draw the attention of other engineers to the simplicity of the processes employed and to free the subject from many of its fancied difficulties.

In regard to the logarithmic chart, with which the paper is chiefly concerned, its properties have been known for a long time, it being now some fifty or sixty years since it was first discussed by Lalanne. Mr. Dodge has contrived, however, to give it a fresh and interesting treatment, and has shown several combinations which will probably be new to most students of the subject.

It is not my intention to add anything on the logarithmic chart to what is contained in the paper, but I should like to direct attention to another chart type which has many interesting features, and which at present seems to be but little understood in this country. I make this digression with more assurance since the title of Mr. Dodge's paper does not seem to limit it to the logarithmic chart alone, and thus makes a discussion of other types permissible.

The type I refer to is that known as the alinement chart.

In Fig. 15 an alinement chart is shown, together with its prototype, on rectangular axes. The lines on *a* of that figure have the general equation

$$ay + bx = c$$

and for the particular case of the solid line shown there it is

$$2y + 3x = 18$$

For $x = 0$, $y = 9$; and for $y = 0$, $x = 6$. These are the points of intersection of the line with the Y and X axes.

Suppose we lay off two new axes, U and V, as at (*b*), making them parallel instead of rectangular. Then join the point 9 on the U axis with O on the V. Also join O on the U axis with 6 on the V. These two lines will intersect at a point distant 18 (to some scale) from the base line. It will be found that if we get the co-ordinates of any point on the solid line in (*a*), as, for instance, $y = 6$, $x = 2$, and lay off 6 on U and 2 on V and join these points, the connecting line will pass through the point of intersection of the first two lines. On the rectangular chart the equation represents a line, while on the alinement chart it represents a point.

If we change the value of c from 18 to, say, 30, we get on (a) the parallel broken line. In the alinement chart it simply raises the point of intersection to the new position shown at 30.

Altering a or b changes the slope of the line on the rectangular chart, but in the other it moves the point of intersection to one or the other side of the vertical.

An equation of the form

$$au + bv = c$$

in which u, v and c are variabls and a and b constants, may be represented then by three graduated lines, and the solution is found on the chart by joining the given values on any two of the axes by a line which cuts the third axis at the required value of the third variable.

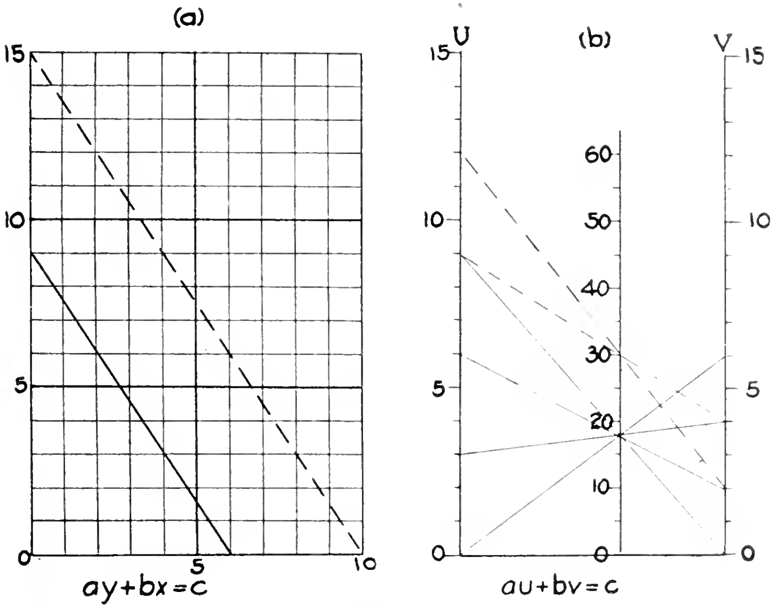


Fig. 15.
Peddle's Diagrams.

With the rectangular chart it is necessary to draw a large number of lines for the various values of c, if close readings are required, and this gives it a confusing appearance. Moreover, if the required value of c falls between the lines instead of on one of them, interpolation is not easy.

With the alinement chart the graduations on the axes may be as fine as we choose, without adding anything to the complexity of the diagram, and, if the index line cuts between two graduations, the necessary interpolation is easily made.

In the equation used above only a simple addition or subtraction of the variables was involved. Multiplication or division is, however, easily performed if, instead of the numbers themselves, we lay off their logarithms on the axes.

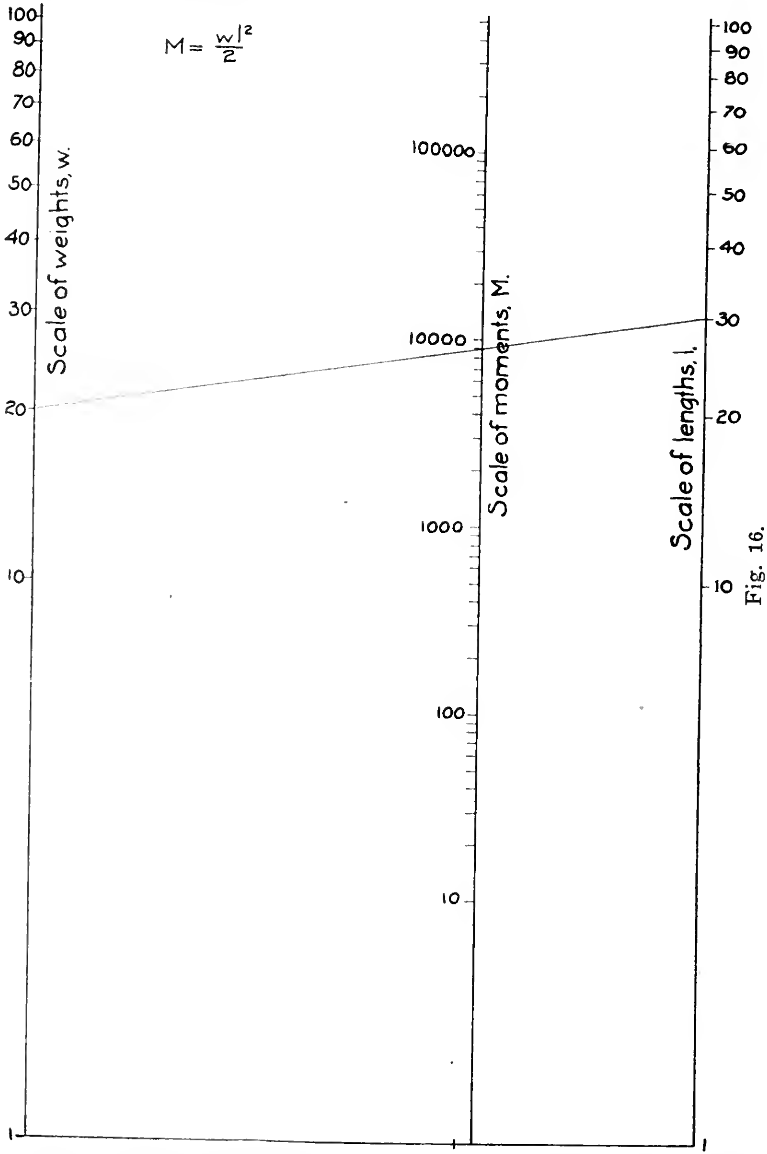


Fig. 16.

Any adequate discussion of the structural details of these charts, such as the choice of scale units, location of the axes, etc., would be out of place here, as it would demand more space than I should be justified in using in the discussion of another man's paper. My only purpose is to call attention to some of the useful features of the alinement diagram, and this, I believe, I can show best by recharting, for the purpose of illustration, some of the equations used by Mr. Dodge.

In Fig. 16 I have used his equation for the bending moment on a uniformly loaded cantilever

$$M = \frac{wl^2}{2}$$

In its logarithmic form it becomes

$$log.\ w + 2\ log.\ l = log.\ M + log.\ 2$$

This evidently agrees in form with our fundamental equation so we plot log. w on the U axis, 2 log. l on the V axis, and log. M + log. 2 on the intermediate axis. To get the moment corresponding, say, to $w = 20$ and $l = 30$, we draw the line shown which cuts the middle axis at 9000.

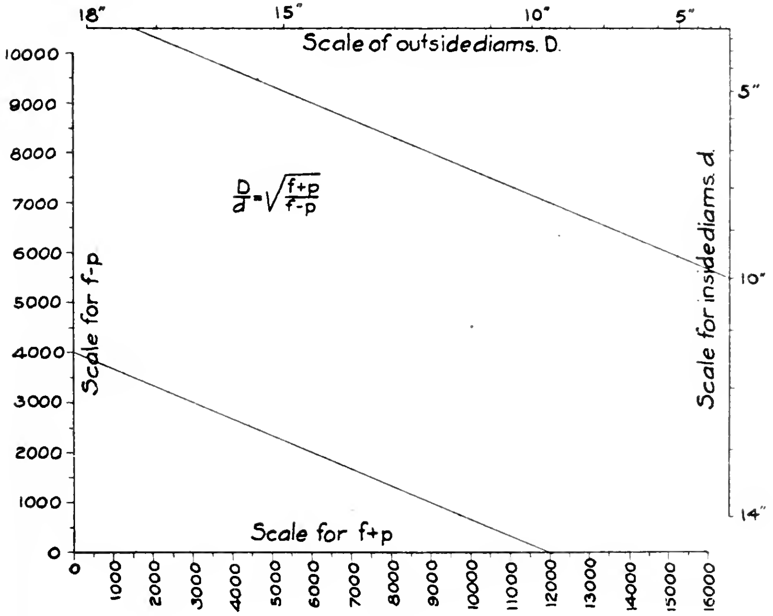


Fig. 17.

For many equations charts which are of the proportional or double alinement type are exceedingly convenient. They differ in principle from the one just described, but as they are true alinement charts they may properly be referred to here.

Take Mr. Dodge's equation for thick cylinders,

$$\frac{D}{d} = \sqrt{\frac{f+p}{f-p}}$$

Square this and it becomes

$$\frac{D^2}{d^2} = \frac{f+p}{f-p}$$

We have here a simple proportion between D^2, d^2 and $f+p$, $f-p$, and there are any number of geometrical constructions which might be used to chart it.

In Fig. 17 four lines are shown bounding a rectangle. On the upper and right hand lines we plot values of D^2 and d^2 respectively. On the lower and left hand lines we lay off lengths to represent $f+p$ and $f-p$.

Now if, for instance, $f = 8000$ and $p = 4000$, $f+p = 12000$ and $f-p = 4000$.

Join 12000 on the $f+p$ axis with 4000 on $f-p$. If we draw a parallel to this line intersecting the diameter axes it will evidently cut them in lengths which are proportional to $f+p$ and $f-p$. If the inner diameter, say, is 10 in. the outer one will be 17.3 in.

The proportional chart has many different forms. One which is often useful is illustrated in Fig. 18. Here we have two pairs of vertical lines, AB and CD, the pairs being equally spaced. It is evident from the construction that

$$a - b = c - d$$

if the index lines are parallel.

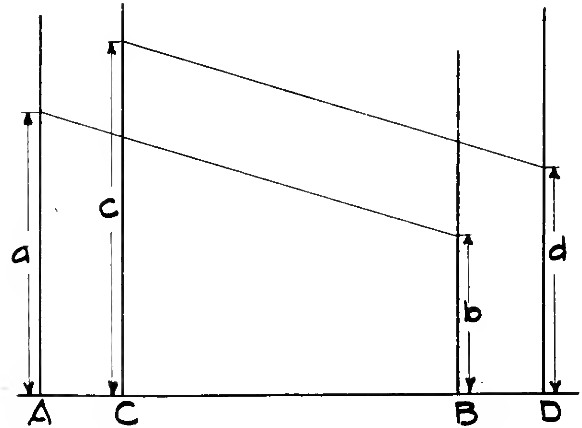


Fig. 18.

The lengths a, b, c and d may of course be the logarithms of the numbers they represent, in which case

$$\log.\ a - \log.\ b. = \log.\ c - \log\ d.$$

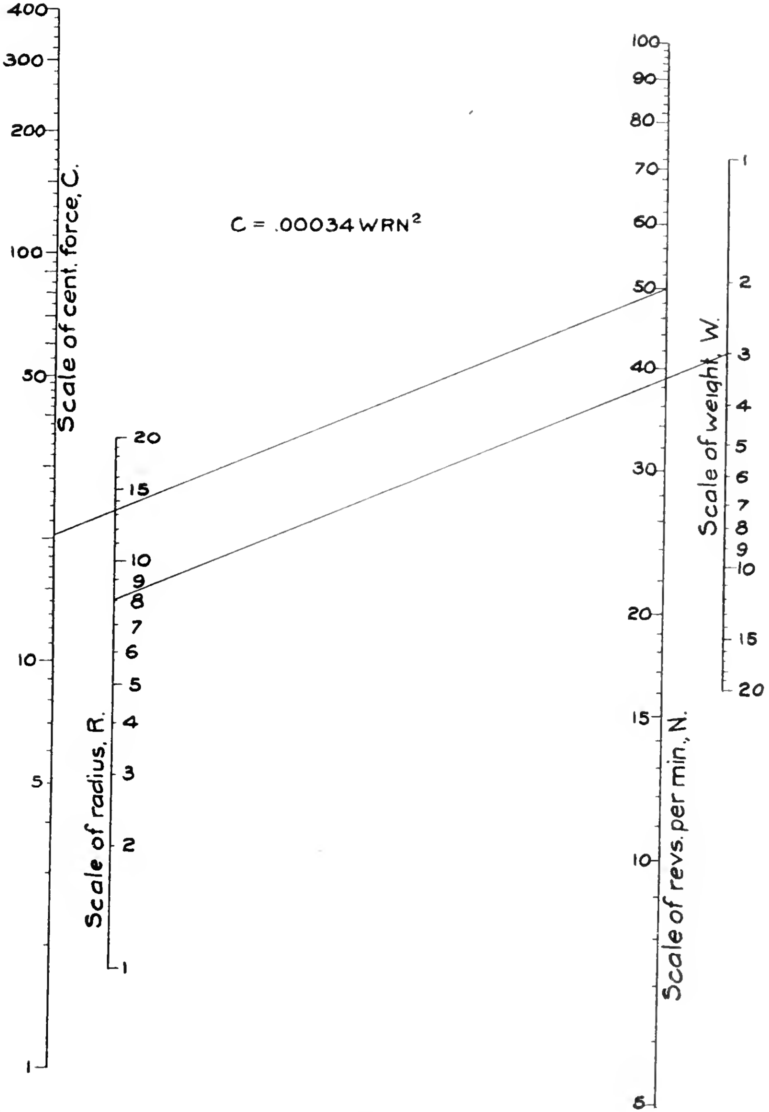


Fig. 19.

or

$$\frac{a}{b} = \frac{c}{d}$$

Thus if the equation we desire to chart can be placed in the form of a proportion, this type of chart may be used.

In Mr. Dodge's paper, Fig. 6, is a chart for centrifugal force. Let us write the equation in the form

$$C = .00034WRN^2$$

In its proportional form it is

$$\frac{C}{.00034N^2} = \frac{R}{\frac{1}{W}}$$

In Fig. 19 this equation has been plotted, log. C on the first axis, log. $.00034N^2$ on the third, log. R on the second, and log. W *downward* on the fourth, remembering that it is $\frac{1}{W}$ and not W which is involved.

Now if we have a weight of 3 lb. at 8 ft. radius, making 50 r. p. m., we join 3 and 8 on the W and R axes and draw a parallel to this line through 50 on the N axis. It cuts C at 20.4.

An interesting variation of the proportional chart is what is known as the Z type illustrated in Fig. 20. The small diagram (a) in this figure may be used to explain it.

From this diagram it is easily seen that

$$\frac{a}{d} = \frac{b}{c} \text{ or } a = \frac{bd}{c}$$

Adding d to both sides we get

$$a + d = \frac{bd}{c} + d = \frac{d}{c}(b + c) = \frac{d}{c}k$$

where k is a constant.

$$\text{Now } \frac{d}{c} = \frac{e}{f}, \quad \text{then } a + d = \frac{e}{f}k$$

This type of equation is not of infrequent occurrence and the formula used by Mr. Dodge for cast iron columns is a good example of it.

His chart was plotted to conform to the equation

$$p = \frac{10000}{1 + \frac{(12L)^2}{800D^2}}$$

p being the safe unit stress, L the length of the column in feet, and D its diameter in inches.

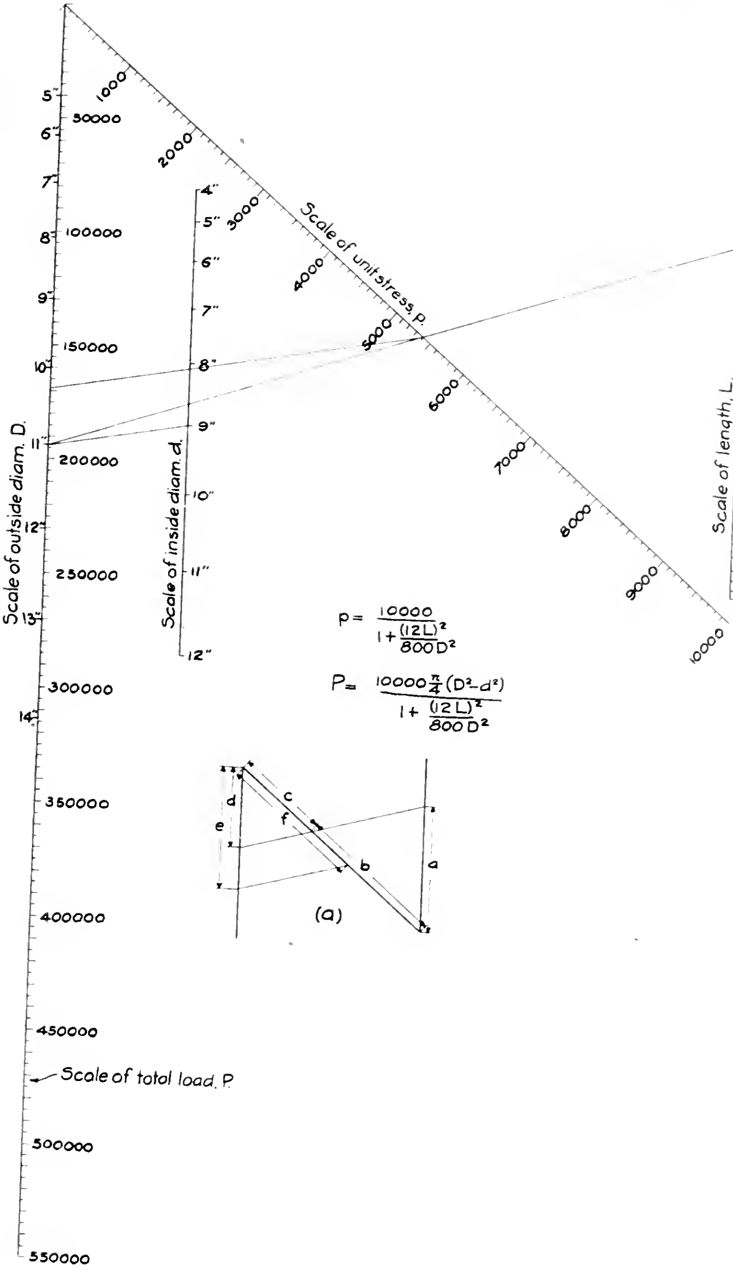

Scale of outside diam. D.
5"
6"
7"
8"
9"
10"
11"
12"
13"
14"
50000
100000
150000
200000
250000
300000
350000
400000
450000
500000
550000
Scale of total load, P
Scale of inside diam. d.
4"
5"
6"
7"
8"
9"
10"
11"
12"
Scale of unit stress, p.
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Scale of length, L.
25'
24'
23'
22'
21'
20'
19'
18'
17'
16'
15'
14'
13'
12'
11'
10'
8
6
$p = \frac{10000}{1+\frac{(12L)^2}{800D^2}}$
$P = \frac{10000\frac{\pi}{4}(D^2-d^2)}{1+\frac{(12L)^2}{800D^2}}$
c
d
e
f
b
a
(a)

Fig. 20.

This equation is easily put into the form

$$800 D^2 + 144 L^2 = \frac{800 D^2}{.0001\, p}$$

This is evidently an equation suited to the *Z* chart, the only difference between it and the fundamental equation being that *D* appears on both sides. This simply indicates that the lengths *d* and *c* on the small diagram (*a*) are equal and we need but one index line instead of the two parallels to read the chart.

We therefore plot D^2 on the left vertical axis, L^2 on the right vertical, and *p* on the diagonal. Then connecting *D* with *L* (say 11 in. with 24 ft.) we find the value of *p* to be a trifle under 5400.

Now suppose we wished to know the total load a given column would support with this unit stress. If *P* is this total load then

$$P = p \frac{\pi}{4} (D^2 - d^2)$$

d being the inside diameter.

This equation may be written

$$\frac{4P}{\pi p} = D^2 - d^2$$

again the same type of equation as the fundamental one and requiring two parallel index lines instead of one for a reading. We have, it is true, a difference instead of a sum of the values D^2 and d^2, but this merely means that *d* must be laid off on the same side of the diagonal as *D* instead of opposite to it.

The *P* scale was laid off on the same axis as *D* and, to permit a large scale unit for *P*, it was necessary to shift the *d* axis away from its normal position as a continuation of the axis of *L*.

Now having *D* and *p* from our first operation (11 and 5400) we join *D* and *d* (say 11 and 9), and parallel to this line draw one through *p* (5400). This intersects the load line (*P*) at about 169000, which should therefore be the total load the column will support.

Ernest McCullough, M. W. S. E (by letter)—It was my intention to discuss this paper at considerable length and take up a number of methods used for the construction of graphical computing charts, other than those constructed on logarithmic ruled paper. That intention, however, has been thwarted by the appearance of the book by Professor Peddle entitled "The Construction of Graphical Charts," wherein every known method of value is set forth and examples given of the construction of charts and also the derivation of empirical formulae from curves representing the results of experiments. However, I do not share with Mr. Dodge his profound admiration for the chart as compared with what he terms "inflexible tables." Charts for aiding computation are very useful and in many cases very valuable. Personally I make limited use of charts and rely more upon the slide rule and "inflexible tables." Mr. Dodge has given to the world a complete book on the design of reinforced concrete structures by means of diagrams, or charts, and it is a monument to his industry and knowledge of the subject. His selection of logarithmic ruled paper for the diagrams which have made him so well known was due to the reasons given in his paper, as logarithmic paper possesses many advantages over other rulings. The average engineer seems to use rectangularly ruled paper in preference to logarithmic ruled paper, presumably because the logarithmic ruling has not been exploited. In plotting diagrams for graphical calculation, I found by actual test that one diagram was made by the use of logarithmic paper in one day which was used for the same purpose as one constructed on rectangular co-ordinate paper which had consumed one entire week of the time of a good man because of the multiplicity of points he had to figure and plot, and the care he was compelled to exercise in drawing curves to fit the plotted points. With logarithmic paper one point was plotted for each term, and the lines were all parallel and at an angle with the horizontal. On the coördinate paper close readings were impossible near the origin, whereas with the logarithmic chart the readings were as close there as anywhere. It is true, as stated by Mr. Dodge, that many more engineers are using graphical methods of computation than has heretofore been the case, and the more light we can have on the subject the better. We will always find men who prefer tables and the slide rule, but there are enough who use graphical charts to make it well worth while to study the matter. For certain purposes a ruled paper has been put on the market in Europe, having the horizontal rulings logarithmic and the vertical rulings equal. Such paper, for example, can be very conveniently used for the construction of alinement charts. Take, for example, one alinement chart described by Professor Peddle for ascertaining areas when the length and width are given. On two vertical lines are plotted, logarithmically, the lengths and breadths. Between them a line is plotted, logarithmically, representing the areas. A thread stretched across the three lines enables one to ascertain any desired area. By the use of "Half-log" paper, much of the labor involved in logarithmic plotting may be saved, and the intermediate line instead of being vertical will be sloping.

O. H. Basquin, M. W. S. E.—Referring to the third page of Mr. Dodge's paper, seventh line from the bottom, beginning, "The reason of this parallelism at 45°," etc., this should be changed, it seems to me, so as to leave out the angle of inclination. That the curve $y = mx$ or $y = mx^2$ passes through zero is sufficient reason for parallelism with various values of m in logarithmic coördinates, but it does not account for the slope, and though both curves have the property of passing through zero, they have different slopes.

Mr. Dodge: The point raised by Professor Basquin is well taken, and the statement he makes that the fact that a curve passes through the origin on ordinary paper does not account for the angle of slope, although it does account for the parallelism of the lines on logarithmic paper, is correct. The slope of the lines is accounted for entirely by the relationship existing between the degrees of the quantities taken as ordinates and abscissas.

The particular equations and formulae used throughout the paper were selected solely for the fact that each brought out some particular condition,—the Lamé formula as giving a solution of but two steps and at the same time showing the effect of plus and minus signs; the formula for centrifugal force showing the treatment for wide ranges and giving a case of one quantity of other than the first degree, while the Gordon formula for columns gave opportunity for showing the extension of the original formula to cover ordinary cases of design.

HIGH PRESSURE WATER SERVICE FOR FIRE PROTECTION

J. B. Sando.

Presented September 7, 1910.

A study of the evolution of fire fighting methods from the early bucket brigade and hand pumping engine down to the portable steam fire engine, of the causes of failure to control fires by these methods, and of the principles involved in the successful systems used for the protection of private properties, indicate that the marked degree of progress made in the protection of our cities against fire, has been accomplished by the development of a system by means of which water can be applied to the seat of a fire in the quickest possible time. The high pressure system of water supply is the natural outgrowth of the desire to accomplish these results.

The limit of bulk and capacity has been nearly reached in portable fire-fighting apparatus, particularly in metropolitan business districts. Some streets, laid out many years ago, are now deficient in width for the accommodation of normal pedestrian and street traffic. With the added congestion due to increased traffic and public excitement at the time of a fire, the efficient manipulation of the large fire engines necessary to cope with conflagrations becomes almost an impossibility. The obvious remedy is an independent system of high-pressure mains and stationary fire fighting apparatus.

Independent high pressure fire protective systems have been in use in American cities for about twenty-two years, and their installation is no longer an experiment. These systems may be divided into three classes, depending upon their method of supply and other local conditions as follows:

First: The gravity system, by which the water is supplied to the distributing mains from reservoirs located on high ground in the vicinity of the area to be protected, such as are at present used in Newark, Providence, Rochester, Fitchburg, Lawrence, Worcester and Washington.

NEWARK, N. J.

At Newark the domestic water service is supplied by means of gravity from three impounding reservoirs on the Pequannock River, located 27 miles from the city, but distributed from a local low service reservoir. The high-pressure fire system is supplied from the Cedar Grove reservoir which is 7 miles distant.

The portion of the domestic service in the district covered by the high-pressure system is supplied from a small reservoir in the city, which only produces a pressure of from 30 to 40 pounds at the hydrants in the business district. The high pressure system has also a gravity supply furnished from Cedar Grove reservoir, its pipe line being laid on a more direct route than the lines of the domestic service and the pressures in it are much greater than in the latter. The difference in elevation between the Cedar Grove reservoir and the street level in the high-pressure district is about 375 feet and this system has been designed to be capable of furnishing at last eight, 300 gallons per minute, fire streams with a pressure of 125 pounds at the hydrants.

PROVIDENCE, R. I.

At Providence the reservoir is so located that a pressure of 116 pounds is available in the mains within the protected area. This system is used to a great extent in connection with automatic sprinklers. Its capacity, however, is not very large, being only about 3,500 gallons per minute. It was installed in the year 1897 and has not been increased since.

This method of supply posseses decided advantages over all others because of its simplicity and economy of operation, but there are very few cities so located that they can take advantage of a gravity system for fire protection.

Second: The pumping systems in which the water is forced directly into the mains by pumps located on fire boats. This was the earliest mechanical system used, being adopted by the city of Milwaukee in 1888, and it has since been applied in Boston, Buffalo, Detroit, Chicago, Cleveland and Duluth.

MILWAUKEE, WIS.

In Milwaukee there are three fire boats each equipped with pumps having a capacity of 5,000 gallons per minute or a combined capacity of 15,000 gallons per minute. There have been laid through the streets of the business section of the city 45,717 feet of special high pressure water mains, varying in diameter from 12 in. to 6 in. The piping system is so arranged that the fire boats can be connected at various points along the lake or river front. The fire boats are equipped with Elmes duplex direct acting pumps 16½ in. by 9½ in. by 12 in., capable of delivering their rated capacities of 5,000 to 6,000 gallons per minute against a pressure of 160 pounds per square inch.

The protected district covers an area of 630 acres and it may be of interest to state that the insurance rates were reduced 10 per cent after the system had been installed and proven satisfactory to the fire insurance companies.

A description of the systems in use in Boston, Buffalo, Detroit, Chicago, Cleveland and Duluth would be needless repetition, as all these cities have installations similar to the one just described for Milwaukee with the exception that the capacities of the fire boats, the area protected and the miles of high pressure mains vary somewhat according to the size of the city.

Though unquestionably valuable, systems of this type are lacking in quickness and efficiency.

Third: Systems in which the water is forced directly into the mains by pumping units located in permanent stations. This system is of proved efficiency when properly designed and operated and is desirable for use in cities where the topographic conditions will not permit of a gravity supply.

As this paper is intended to particularly describe this system, for convenience I will divide the type of pumping machinery used in permanent stations as follows:

(I) Positive displacement pumps.
(II) Pumps of the rotary type.

The positive displacement pumps may be subdivided as

A. Steam engine driven { a—Crank and flywheel, or
  b—Direct acting.
B. Gas engine driven
C. Electric motor driven.

BALTIMORE, MD.

A. For the steam engine driven positive displacement pumps, the most notable example is that of the units now being installed in the city of Baltimore, Maryland. They consist of three horizontal Corliss twin, simple crank and flywheel pumping engines and one horizontal duplex direct-acting compound pump, together with boilers and all appurtenances.

The crank and flywheel pumping engines have the water ends attached directly to the engine frame at the opposite end to the steam cylinders, and the flywheel is located between the steam and water ends. All the cylinders are 22 in. diameter by 36 in. stroke, fitted with Corliss valve gear having a double eccentric long range cut-off.

Each pumping engine is designed for a continuous working pressure of 300 pounds per square inch on the discharge, with pressure on the suction varying from 15 feet lift to 50 pounds pressure. Steam of 125 pounds gauge pressure is available at the engine throttle when a water pressure of only 150 pounds is desired, but when the full 300 pounds is required, then the steam pressure will be increased to 150 pounds gauge. Each engine is normally capable of delivering 3,000 gallons per minute against a pressure of 300 pounds and 15 feet suction lift, with a piston speed of 225 feet per minute and with a cut-off not exceeding 60%. The flexibility of these steam engines makes it possible to greatly increase the speed and capacity of the pumping units as emergency requires.

Under the normal rating these pumping engines, which are operated non-condensing, must develop 70,000,000 foot-pounds of work or duty per 1,000 pounds of dry steam supplied to the engine, simplicity and reliability being of greater importance than economy in fire fighting apparatus.

Each engine is equipped with speed and pressure governors, the former driven by a silent chain belt, each acting directly on the cut-off valves of both cylinders and are capable of instant adjustment for any water pressure, varying from 100 to 300 pounds per square inch, so that the engines are at all times under control of the pressure governors, as well as the speed governors, when operating with varying water pressures. Connections from the pressure regulators are led to a common point within the engine room from which point any one or all of the engines can be quickly set to operate against any water pressure between 100 and 300 pounds.

The water ends of each unit consist of 2 double-acting divisions or 4 separate pump chambers, 2 chambers or one division being placed directly in line with each steam cylinder. The pump chambers are piped separately to the suction and discharge mains. These chambers, although designed for a working pressure of 300 pounds per square inch, will withstand a test pressure of 600 pounds per square inch, and for this reason are made of cast steel.

The valve decks of both suction and discharge are made of cast steel. They are separate castings from the chambers to which they are bolted. The valves are made of the best quality of rubber composition. The valve seats are made of bronze and are screwed into the valve decks on a taper.

The water plungers are made of cast bronze and connected to the cross heads by means of Tobin-bronze plunger rods running entirely through the plungers and securely fastened at both ends.

Large air chambers, made of cast steel, are placed directly over each set of discharge valves to insure an easy action of the pumps and to prevent injury due to water hammer caused by a sudden fluctuation of the pressure throughout the system. These air chambers are charged by an independent air compressor.

The horizontal duplex direct acting pump has a capacity of 1,000 gallons per minute, at a plunger speed not exceeding 100 feet, or 67 strokes per minute, against 150 pounds water pressure with 125 pounds steam pressure.

The steam cylinders are arranged with the low pressure cylinders outboard and the high pressure cylinders inboard or next to the water end. There are two piston rods from each low pressure steam cylinder and one piston rod from each high pressure steam cylinder, leading to a cross head, to which is also connected the plunger rod.

The steam valves are placed on the under side of the steam cylinders and are of the semi-rotative type.

The water end is of the outside center-packed plunger type, suitable for a working water pressure of 300 pounds, and a test pressure of 600 pounds per square inch.

The water valves used on this pump are practically the same as those used on the crank and flywheel pumping engines.

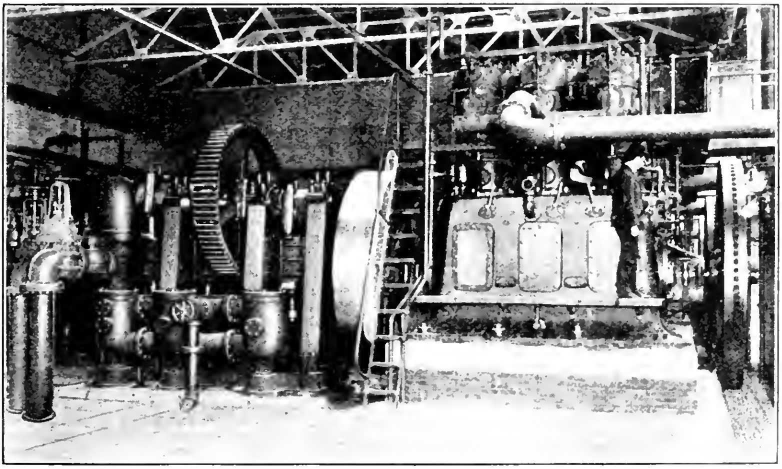
The discharge pipe is provided with a cast steel air chamber which is also charged by means of an independent air compressor.

The steam cylinders are 14 in. and 25 in. diameter by 16 in. stroke, and the unit develops 45,000,000 foot-pounds of work or duty per 1,000 pounds of dry steam delivered to the steam end when operating under full normal load conditions.

B. There are two installations which are good representative examples of permanent stations for high pressure fire service, in which gas engines have been employed as prime movers, namely, at Philadelphia and Coney Island, and it is these stations that I will next describe.

PHILADELPHIA, PA.

In Philadelphia the high pressure service system draws its water supply entirely from the Delaware River, the pumping station being located near the river front. After having its pressure raised to the required amount, the water passes into a 20-inch distributing main along the river front, which supplies 12 and 16-inch mains extending into the business district. Stop valves at every corner, or at intermediate points, provide means for localizing damage due to a ruptured section of piping, thus avoiding the crippling of more than one hydrant. Each hydrant has two 4-inch nozzles, to each of which manifold connections may be attached, supplying in all six hose lines.



300 B. H. P. Westinghouse-Deane Gas Engine Pumping Mint, Philadelphia.

Telephone boxes are provided at each street intersection, communicating with the central office at fire headquarters, from which operating orders may be transmitted to all points of the system.

The engine room of the pumping station is approximately 130 ft. by 68 ft., including the basement, and is spanned by a 6-ton traveling crane.

At present the station contains twelve pumping units, of which ten are 300 B. H. P. 2,000,000 gallons, and two are 125 B. H. P. 750,000 gallons capacity. In addition to the pumps, each of the smaller engines drive an igniter-generator and air compressor.

The gas supply of the plant is drawn from a 30-inch trunk main connecting two of the largest gas holders of the city's illuminating gas system.

The engines are all of the vertical, three-cylinder, single-acting type, operating upon the four-stroke cycle, thus giving a power stroke at each two-thirds revolution. They are of the enclosed or self-contained type of construction, the shaft, cranks, and connecting-rods being inclosed in a housing provided with suitable manholes for ready access to the working parts. This housing is filled with oil to such a height that the cranks during their revolutions dip into this oil and furnish splash lubrication for all interior working parts. The cylinders, each provided with water jackets for cooling, are mounted directly upon the housing, and contain long trunk pistons, thus dispensing with the usual engine crosshead.

A platform extends around the engines at about 10 feet from the engine room floor, serving as a working platform for operating the engine throttles and inspecting the valve gear. The platforms are interconnected between engines, so that a continuous runway is formed extending from one end of the power station to the other. Upon this gallery are mounted the igniter cabinets. A sub-platform is also bolted to the engine for convenience in operating the air-starting mechanism.

The arrangement of the valve mechanism is such that a charge of explosive mixture is admitted to the cylinder at every other stroke, which is in turn ignited at the beginning of the succeeding stroke. The proportioning of the power generated, to the load upon the engine, is performed by a centrifugal governor operated through gearing from the crank shaft. The governor controls the admission of a variable quantity of mixture to the cylinders according to the load.

Ignition of the mixture under compression is accomplished by an electric igniter of the "make and break" (sometimes called "hammer") type, removable for cleaning in the form of a single plug. Two igniters are supplied to each cylinder for increased surety of operation, and by means of a throw-over switch the ignition current may be transferred to the reserve igniter on any cylinder.

The starting of the engines is accomplished through the agency of compressed air at 150 to 200 pounds pressure. The pumps are arranged for starting without load, and the work done by the engine is that of friction alone.

In starting, the valve mechanism of the end cylinder is temporarily isolated by means of a lever which the operator manipulates. With a second lever, compressed air is admitted to the cylinder, which acts as an air motor. In three or four revolutions the normal explosion cycle is started in the remaining cylinders, the compressed air is shut off, and the exhaust valves in the end cylinder are thrown back into action by the lever above mentioned.

The ignition current supply constitutes one of the most vital points in the operation of the engines. Each engine is furnished with an igniter cabinet which is located close to the engine throttles upon the upper galleries.

Three independent sources of current are intended to be available at each cabinet, and are there controlled by switches. A running current is regularly supplied from a duplicate set of 7½ kw. 220 volt, direct-current generators, belted to the smaller engines. This voltage is reduced to 110 volts by individual motor-generators. The igniter current may, however, be drawn directly from the 220 volt station main, in case of emergency. If both station generators fail, 220 volt Edison current is available for the motor-generators, and finally, current at 8 volts from primary cells in the cabinet can be sent direct to the igniters.

Sufficient compressed air must be kept continually stored in tanks to start the entire station without aid from the air compressor. The air is furnished by a duplicate set of two-stage compressors, each provided with an automatic unloader valve which opens above 200 pounds pressure and relieves the pump from duty, although it may still be in operation. If the pressure falls below 200 pounds, the valve again places the pump in action. The air is stored in eight seamless steel tanks 16 inches in diameter and 15 feet long, having an aggregate capacity of 164.4 cubic feet.

The pumps are of the triplex, double-acting, inside packed plunger type and were built by the Deane Steam Pump Company of Holyoke, Mass.

An important feature is the provision of a motor-driven bypass valve, controlled from positions in the centre aisle in front of the gauge boards. This valve is left open during the starting of the unit, and when full speed has been reached, it is gradually closed by the motor and diverts the pump discharge from the overflow to the station discharge main, leading to the high pressure system. This operation allows the pump to start up under a friction load, and the discharge pressure is gradually increased to full working pressure during the closing of the valve, thus avoiding all shock to the machinery or system. It also does away with the clutch coupling, which would otherwise be necessary.

An automatic relief valve upon the discharge chamber of the pump serves to protect the latter against excessive pressure. This valve is used during the daily tests of the equipment, to obtain the normal working pressure when the pump discharge is throttled by the by-pass valve. A check valve in each discharge protects the idle pump against back pressure from other pumps in operation.

The smaller pumps are similar in equipment to the larger ones, with the exception that a friction clutch is used in place of the by-pass. This is necessary, as the engines are also used for driving auxiliaries.

The average time required for placing the entire station in service is about sixty seconds per unit or a total of ten minutes from the time of signal from fire headquarters.

CONEY ISLAND, N. Y.

On account of the frequent fires at Coney Island, N. Y., which on several occasions have practically destroyed the greater part of the amusement places at this resort, it was necessary for the city officials to devise some means for better fire protection than could be given by the city fire department, with the limited facilities at their command. A high-pressure fire system was accordingly constructed capable of delivering 4,500 gallons per minute, with a pressure at the pumps at 150 pounds per square inch, yielding a pressure at the fire hydrant of at least 125 pounds when full capacity of the station is utilized. This capacity, namely, 4,500 gallons per minute, is sufficient to supply 15 fire streams of 250 to 300 gallons per minute.

The nearest electric generating plant is six miles distant, while a gas holder is located about 3,000 feet from the site of the pumping station which is a one-story brick building built on heavy concrete base laid on a pile foundation. The building is 37 by 62 feet, located on the Coney Island creek and the floor level is about four feet above mean high tide.

In this building are installed three Gould triplex, double-acting, piston pumps. Each pump is direct connected to and driven by, a Nash vertical three-cylinder gas engine. A special 16-inch high pressure main leads from the pumping station to the main avenue of the protected area and along this avenue in both directions to the limits of the district. Several 12-inch branches are laid under the walks leading out toward the beach and a number of private connections have been made for fire protection only.

Fresh water is supplied to the pumps from two separate sources, each being furnished by a storage reservoir in the city. Suction connections have also been made, so that salt water may be drawn from Coney Island creek in case of an emergency.

As is the case in Philadelphia, each pump is fitted with a by-pass connecting the discharge from the pumps with the overflow pipe. This by-pass is controlled by an electrically operated gate valve, which is open when the engine is started and gradually closed when the engine has attained full speed.

The three gas engines are adapted to the use of illuminating gas. The cranks on the crank-shaft are set at 120° apart, so that the impulses follow each other at regular intervals. The cylinders are 13¾ inches diameter by 16-inch stroke. The engines run at 260 revolutions per minute, developing 175 horse-power each, and using at that load, it is stated, about 17.4 cubic feet of gas per brake horsepower per hour, when gas containing about 590 B. t. u. per cubic foot is supplied.

The igniting devices are supplied with electric current from primary batteries and also from small electrically driven dynamos in the station.

Compressed air is here also used for starting the engines and is supplied by one or both of two separate air compressors, one compressor being driven by a separate gas engine, and the other being driven by one of the main engines. This air is kept in storage tanks having a sufficient capacity, it is said, to start all engines twice. The manipulations necessary for starting these engines are identical with those required in Philadelphia which consist of seven different operations, namely:

1st.—Closing ignition switch.
2nd.—Opening engine throttle.
3rd—Throwing compressed air valve.
4th.—Throwing exhaust valves.
5th.—Turning on cooling water.
6th.—Opening suction valve.
7th.—Closing motor switch on "by-pass" valve.

The water in the mains and hydrants is always maintained at the ordinary city service pressure, which is about 50 pounds per square inch. When an alarm of fire is turned in at the pumping station, the engineer starts one engine and pump, raising the pressure in the system at the pump to 150 pounds per square inch, and the other engines and pumps are started as the demands on the system may require. The time here required for starting a unit, under the most favorable circumstances, is also about one minute.

Having described in more or less detail the two high-pressure fire service systems in which gas engines are used as the prime movers in the permanent station, your attention is invited to several important points which should be seriously considered.

First. The number of operations necessary to start gas engines when they are obliged to be put into quick service for fire protection.

Second. The uncertainty of the invariable operation of the motor driven gate valve placed in the discharge pipe which must be opened and closed each time the pump is started.

Third. The possibility of a failure in either the air compressors or air storage tanks, thereby making it practically impossible to start the gas engines without a considerable expenditure of time.

Fourth. The possibility of failure in the ignition system.

For the rotary type of fire pump which I have previously only mentioned, the following subdivisions may be made:

I. Positive displacement rotaries	a.—Steam driven. b.—Electric-motor driven.
II. Centrifugal pumps	a.—Steam-turbine driven. b.—Electric-motor driven.

The steam fire engine is perhaps the best example of the steam-driven, positive-displacement, rotary pump. The writer can find no record of electric-motor driven, positive displacement, rotary pumps used for permanent fire protective systems, although such a combination might be employed.

SAN FRANCISCO, CAL.

The city of San Francisco, California, has recently installed a fire protective system in which pumps of the steam-turbine driven, centrifugal type have been employed. Although San Francisco's equipment is in reality a combination of all three of the principles, namely: gravity, fire boat, and permanent station, nevertheless the city relies mainly for protection on the permanent station.

The protected area is divided into an upper and lower zone. Each of these zones is supplied with water through an independent distributing system, but they may be connected into one in case of an emergency. Two storage reservoirs, each having a capacity of 5,000,000 gallons, are located on Twin Peaks which is the highest point in the city. Their capacity is equal to the continuous delivery of 15,000 gallons per minute for about eleven hours; for shorter periods of time greater quantities can be delivered. They were constructed by making excavations of the required shape in the rock and lining the sides and bottom with concrete.

Two lines of 20-inch pipe connect these reservoirs with the distributing system and to the distributing reservoirs which will be described later.

Under ordinary conditions only one reservoir is connected with the distributing mains. Then in case of a sudden break in the pipe line, it is impossible for the supply in more than one reservoir to be wasted.

The elevation of these reservoirs is such that they provide a pressure in the mains higher than required for fighting ordinary fires. As this pressure is only used on rare occasions water is not supplied directly to the system from these reservoirs.

It is in order that the various districts may be provided with sufficient water for use at ordinary fires, under moderate direct pressure, that the protected area as previously mentioned, is divided into two zones. The lower one includes approximately that section lying below the 150 foot contour; the remainder is in the upper zone. Each zone is directly fed from a distributing reservoir.

The reservoir supplying the upper zone has a capacity of 500,000 gallons and is located at an elevation of about 490 feet. The water supply is obtained from the Twin Peaks reservoir by gravity flow through the two lines of 20-inch pipe, or it can be pumped directly from the fresh water pumping stations.

The lower zone is supplied from a reservoir of 1,000,000 gallons capacity; the elevation of the water surface is about 329 feet. The water supply for this reservoir may be pumped directly from the fresh water pumping station, or it may be obtained by gravity flow through the distributing system from the distributing reservoir of the upper zone or from the storage reservoirs on Twin Peaks.

A gate house with the necessary pressure gauges, meters, and telephone connections is located at each distributing reservoir. Men, detailed from nearby fire engine crews, to operate the gates, are on duty at all times.

When, in either zone, the necessity arises for the use of a pressure in excess of that provided by its distributing reservoir, the pressure may be increased up to the full pressure from the Twin Peaks reservoirs by operating the proper gates at the gate houses to by-pass the flow around the distributing reservoirs.

The storage and distributing reservoirs are supplied with fresh water from groups of bored wells, from which water is pumped through the mains of the distributing system by pumps installed in two fresh water pumping stations. These stations, which are identical in design, are located near Harrison and Seventh streets and Sixteenth and Shotwell streets, respectively. The wells from which they draw the water are bored at intervals of about 70 feet in the adjacent streets.

The water from the wells is raised to the surface and delivered into a reinforced concrete cistern of 175,000 gallons capacity, situated under each pumping station, by air pumps of the Pohle Air Lift type. These pumps consist of air compressors in each station, a separate air pipe from the stations to each well, and water pipes in the wells and leading therefrom to the cisterns. It is well known that pumps of this type are very inefficient in regard to the amount of power necessary for their operation, but their simplicity and the consequent low cost of maintenance for intermittent service outweighs this objection.

The mechanical equipment of each station consists of the following apparatus:

Two duplex air compressors, each capable of compressing 600 cubic feet of free air to a pressure of 80 pounds per square inch.

Two 100 H. P., electric motors to drive the above air compressors.

Two 3-stage turbine centrifugal pumps, each driven by a 75 H. P. electric motor connected directly to its shaft. The capacity of each of these pumps is 525 gallons per minute against a head of 330 feet.

Two 5-stage turbine pumps, each driven by a 125 H. P. electric motor connected directly to its shaft. The capacity of each of these pumps is 525 gallons per minute against a head of 500 feet.

This equipment together with traveling crane, air receivers, piping, switchboard and automatic recording instruments completes the installation.

The discharge pipes from each station are connected to the distributing mains of the lower zone and water is pumped into the various reservoirs through these mains, the gates connecting the upper zone and the Twin Peaks reservoir being opened as required. For delivering into the Twin Peaks reservoirs, the three and five stage pumps are operated in series, the three stage pumps discharging into the suction side of the five stage. For the reservoir of the upper zone, the five stage pump is used, and for the reservoir of the lower zone the three stage.

Two salt water pumping stations have been constructed near the bay shore, one near the northerly termination of Polk Street and Van Ness avenue, the other in the vicinity of the intersection of Second and Townsend streets.

Each station is of sufficient size to provide for the installation of machinery to pump 16,000 gallons per minute against a pressure of 300 pounds per square inch. There is at present, however, installed in each station sufficient machinery to pump only 10,000 gallons per minute against the said pressure. At the time these pumping stations were being considered, a study of the different types of pumping machinery was made. The types of motors considered for driving the pumps were divided into three classes, Steam Engines, Internal Combustion Engines, and Electric Motors.

Electric motors operated by current from wires of private electric companies could not be used, as the stations are so located that power was not available. Therefore, in order to compare the relative economy of the *Steam Engine* and *Internal Combustion* engine, two sets of plans, together with estimates of the cost of installation and operation of the pumping stations, were prepared. It was proven in a manner thoroughly satisfactory to the engineers, making the investigation, that the steam driven type of installation was preferable, owing to the facts that suitable fuel could be stored with greater safety, greater simplicity of mechanical equipment could be obtained together with greater reliability, and the fact that men competent to operate such a steam plant are always available.

At this point it may be well to explain why it is that the centrifugal pump has been so generally adopted for fire service. The principal reason is that it is the most simple type available for this service. A number of runners or impellers, one for each stage or degree of lift, are mounted directly on the driving shaft and rotate at high speed inside of a suitable casing. The high speed feature makes them particularly advantageous to use direct connected to steam or hydraulic turbines or electric motors, thereby eliminating all the serious troubles which are inherent in gear or belt drive. There are no moving valves in the pump, and the only parts subject to wear are the bearing, packing glands, and wearing rings between the runner and the casing. The wear on these parts is small, and in case of necessity they may be readily repaired and at a minimum expense.

Another feature in favor of the centrifugal type of pump is that the closing of the valve on the discharge pipe through accident or design while the pump is running, will result only in a slight rise of the pressure in the discharge side of the casing, whereas a similar occurrence in the case of a plunger pump is likely to result in the breakage of some part of the pump, or of the engine driving it. An effort is usually made to protect positive displacement pumps from such accidents by providing a safety valve on the discharge side which will raise and relieve the pressure when it becomes too high. These valves are liable to stick, and a plunger pump so equipped does not offer the same safety of operation as a centrifugal pump.

It is admittedly the case, that centrifugal pumps are not economical for continuous operation, as in waterworks service, but for fire protection this consideration is far outweighed by the advantage of simplicity and quickness of starting.

Each station now contains the following mechanical equipment:

Four water tube boilers arranged in batteries of two, each battery being fitted with a separate smoke stack 6½ feet in diameter and 82 feet high. Space has been provided for the installation, when necessary, of two additional boilers. The steam piping is arranged so that an accident to a part will not disable the entire plant.

There are five pumps of the multi-stage centrifugal type, each capable of delivering 2,000 gallons of water per minute against a pressure of 300 pounds per square inch when running at a speed of about 1,800 revolutions per minute.

Each pump is directly connected to the shaft of a steam turbine capable of developing 600 B. H. P. continuously and of carrying an overload of 25% for short intervals. Arrangements have been made so that by varying the speed of the turbine or by opening valves in the discharge side of the pump, the pressure against which the pump is working may be varied between 150 and 300 pounds per square inch.

A surface condenser containing 2,400 square feet of cooling surface has been installed at each turbine for the purpose of condensing the exhaust steam. The entire capacity discharge of the centrifugal pump, to which the steam turbine is directly connected, is passed through the condenser and is used as the cooling water.

Since the boilers are provided with oil burners, each station has eight fuel oil tanks having a combined capacity of 2,000 barrels. These tanks are placed in fire proof compartments adjacent to the pumping station. It is estimated that this is sufficient fuel to run the station under service conditions for four weeks and retain a reserve supply for forty-eight hours' continuous operation, at the ultimate capacity of the station.

A fresh water cistern of 50,000 gallons capacity has been installed for storing fresh water for making up loss in the feed water for the boilers. In addition there has been provided tanks for the storage of lubricating oils.

Feed pumps, fuel oil pumps, electric lighting plant, feed water heater, suction and discharge piping with valves, Venturi meters, automatic registers, recording devices, and a 10-ton electric traveling crane complete the mechanical equipment for each station.

Together with the apparatus just described, the city has also provided two twin-screw, steel fire boats, equipped with apparatus for fighting fires along the water front. These sister ships are each 129 ft. long, with 26 ft. beam and 12 ft. 9 in. depth. Each boat is equipped with three main turret nozzles, one above the pilot house, one amidships above the deck house, and one mounted on a structural steel tower. Besides these, there are twenty valves for auxiliary streams, which are placed amidships above the deck house, and in addition there are two portable two-inch nozzles.

Water is furnished by two sets of fire pumps, each set consisting of two 2-stage centrifugal pumps directly connected to, and driven by, 600 H. P. steam turbines. These pumps may be operated either in parallel or in series, each pumping set delivering 4,000 gallons per minute against a discharge pressure of 150 pounds per square inch, when operated in parallel, or 2,000 gallons per minute against a pressure of 300 pounds per square inch when operated in series. As there are two sets in each boat, the total discharge capacity of a boat will be 8,000 gallons per minute against 150 pounds per square inch, or 4,000 gallons per minute against 300 pounds per square inch.

The two main engines for propelling each vessel are of the vertical compound type with 13-inch high pressure and 28-inch low pressure cylinders, being fitted with Stevenson link motion and steam reversing gear. On their trial trips, each boat developed a speed of 13 miles per hour.

Steam is furnished by two Babcock and Wilcox water tube boilers, with a combined heating surface of 5,400 square feet, constructed for a working pressure of 200 pounds per square inch. Oil is used as fuel.

The turbines are operated with a steam pressure of 150 pounds per square inch, and are provided with an automatic governor driven through positive gearing from the turbine shafts. The turbines exhaust into surface condensers, having 1,350 square feet of cooling surface. Circulating water is provided for the condensers by means of a centrifugal pump having a capacity of 2,000 gallons per minute and directly connected to a single cylinder, vertical engine.

The three main fire nozzles, or monitors, deliver a 3-inch stream and, as was stated, are mounted on the pilot house, on the deck house, and on a water tower. The water tower is 26 feet high above the upper deck and consists of a square latticed column with a 4 ft. base and 2 ft. top.

The boats are electrically lighted and are each provided with an 18 in. searchlight. In addition, the boats are furnished with a full equipment of compasses, life boats and davits, life preservers, life buoys, lights, anchors and chains, all to comply with the Rules and Regulations prescribed by the Board of Supervising Inspectors of the United States Steamboat Inspection Service.

The one installation for fire protective service which has undoubtedly been of the greatest interest to engineers throughout this country, and the design of which, due to its great success, is now being followed by practically all the cities in the United States which are considering the high pressure systems, is the one which will now be described. This installation is also a very good example of electric motor driven centrifugal pump type of apparatus.

NEW YORK, N. Y.

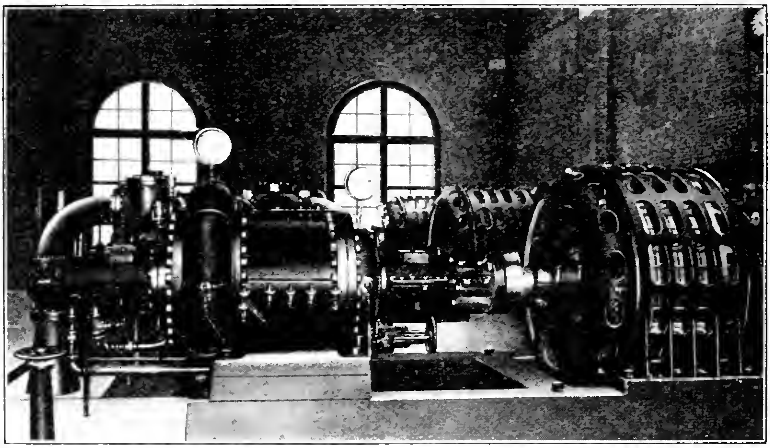
The high pressure pumping system installed for fire service in the city of New York protects the district extending north from City Hall to Twenty-fifth street, and east approximately from the North River to Second avenue. It comprises about 55 miles of extra heavy cast iron mains, from 12 inches to 24 inches in diameter, with 8-inch hydrant branches, and two pumping stations so located that they never can be in the center of a conflagration. At the present time, the pumping stations have a combined capacity of over 30,000 gallons per minute delivered at a pressure exceeding 300 pounds per square inch.

The two stations, known as the Gansevoort Pumping Station, located near Gansevoort Market on the North River, and the South Street Station near the East River, are identical in construction and equipment. The buildings are of simple design, of steel fire proof construction, with concrete foundations. The Gansevoort Street building, which is typical of both, is one story high with basement, 63 ft. 8 in. by 97 ft. 4 in. Each station is large enough for 8 pumping units, although the present installation consists of only 5 units at each station. In the floor plans of the buildings and general layout of machinery, piping, switchboards, etc., space is provided for three additional units. The arrangement is the same for both stations, the only difference being that the switchboard and office in the South Street Station are on different sides of the building as compared with the Gansevoort Station.

The motors and pumps, with suction and delivery branches, are located on the main floor of the pump room. The switchboard and switchboard apparatus are placed in an enclosed two-story and basement gallery. The four high-tension feeders and all other wires entering the building are brought in through the gallery basement, and all terminal work on the entering wires is located in the basement. On the first floor of the gallery, which is approximately on the same level as the pump room floor, are placed all oil switches, with their controlling and protective devices, fireproof cells and compartments. The operating switchboard is conveniently located on the enclosing wall of the gallery, and is so placed as to allow a man standing on the pump room floor to perform all operations necessary for controlling the apparatus in the station. The bus bars, with their fireproof compartments, are placed on the second floor of the gallery.

The five units in each station consist of Allis-Chalmers 5-stage centrifugal pumps driven by induction motors, and the necessary auxiliary machinery. All the motors and pumps are alike and their parts are interchangeable. The pumps each have a specified capacity of 3,000 gallons per minute, and a delivery pressure of 300 pounds per square inch. The actual capacity, as indicated by a 24 hour test, was about 30% in excess of that specified.

The original specifications contemplated the use of 6-stage pumps, with the expectation that sea-water would be used at each fire. Because, however, the relative amount of water required for fire purpose is insignificant and sea-water may do considerably more damage to goods than fresh water, a change in the specifications was agreed upon, whereby the pumps should work at best efficiency when receiving water from the Croton mains at a pressure on the intake side varying from 15 pounds to 40 pounds per square inch. To meet this new condition, the pumps were all built with five stages. All the sea connections and priming as originally contemplated were installed so that sea-water can be pumped into the mains whenever desired. The effect of the change is merely to reduce the pressure head slightly in case sea-water is used.



Motor Driven Centrifugal Pumping Unit, 3000 G. p. m. @ 300 lb. Pressure, New York High Pressure Fire Service System.

Each pump is directly connected to its motor by a flexible coupling, which takes care of any variation from alignment. The motors are of the constant speed induction type, 3 phase, 25 cycle, 6,300 volt to 6,600 volt, designed to operate at about 740 revolutions per minute. The motors are of the wound rotor type and, in starting, an iron grid resistance is connected in the secondary circuit and gradually cut out by means of a hand wheel on the motor switchboard panel. When the resistance is all cut out, the rotor is automatically short circuited and governed by specially constructed solenoids which are operated by a small switch mounted directly on the shaft of the hand wheel above referred to. An interlocking arrangement prevents the operator from closing the switch connecting the motor to the line while the rotor is short circuited.

The specifications required the motors to have sufficient starting torque to attain full speed between 30 and 45 seconds after starting, with a current not exceeding 150% of that used when the motor is working under full speed. Each motor was required to develop not less than 800 B. H. P. when using current of 6,300 volts, 25 cycles, and under these conditions to have an efficiency not less than 92%, a power factor not less than 93%, and a motor slip not in excess of 2%. At ¾ load, the efficiency was to be not less than 92% and the slip not to exceed 1.5%. It was specified that the temperature of the motors should not rise more than 40% on a 24 hour test at full load, when measured by a thermometer, the air in the room being 25 deg. C.

Professor George F. Sever, of Columbia University, tested two of the motors in the shops of the contractor, and found them to meet the specifications, to have a full load efficiency of 93.2%, and the slip at full load approximately 1%. The other motors were inspected and found to be alike and were assumed to have the same efficiency. The motors were tested at the time of the official tests and came within the heating guarantees.

The pumps were constructed with five stages, each to give a pressure of somewhat over 60 pounds per square inch, making the combined pressure of five stages about 300 pounds per square inch above the intake pressure; this is the maximum working pressure of the stations, at normal speed of 740 revolutions per minute.

The pumps are water-balanced by a piston connection to the last impeller and upon which the water pressure acts, but should any additional end thrust occur, it would be taken up by the ball bearing provided in the outboard bearing. This ball bearing consists of two rings of 1½ in. diameter steel balls, and is water cooled. The balancing piston is fitted very loosely in order to keep the friction losses small, and as a result a considerable amount of water leaks past into a chamber at the end of the pump, which is provided with a discharge pipe and valve leading into the suction. By adjusting the valve in this pipe, the difference of pressures on the piston can be regulated as desired.

The bearings are of the ring-oiled type and are separated from the pump casing by packing glands which prevent foreign matter from entering the bearings. The impellers are of bronze and the shaft of forged steel. All parts of the impellers and diffusion vanes are thoroughly lubricated by grease cups on the base of the pumps. A feature is the wide base which allows the pump barrel to be set low, giving stability. Each combined unit is equipped with automatic and hand control. The pumps are kept primed for constant service, and the simple operation of a switch on the main switchboard starts the machine and gives full pressure in about 30 seconds.

A combined regulating and relief valve is interposed between the discharge pipe and suction pipe of each pump, and set to regulate the discharge of each pump to any predetermined pressure. When the volume of water discharged by the pump is in excess of that forced into the system, this valve acts as a relief valve and by-passes this excess into the suction of the pump, the pressure on the main distributing system remaining at the predetermined point. When no water is forced into the distributing system, all of the water discharged from the pump is by-passed into the suction. The pressure regulating valves were made by the Ross Valve Manufacturing Company of Troy, N. Y., and much of the practical success of the station has been due to the accuracy with which these maintain any desired pressure.

The priming apparatus in each station consists of three motor driven vacuum-pumps, each arranged to maintain automatically a vacuum of 26 inches of mercury in the suction lines. These pumps are of the single acting piston pattern, one having a displacement capacity of 300 cubic feet per minute for a piston speed of 200 feet per minute, and each of the others a displacement capacity of 50 cubic feet with a piston speed of 160 feet per minute.

An air collecting chamber is connected to each of the salt water suction lines and equipped with water gauge glass and vacuum gauge. The air suction piping between the air chambers and the air pumps is provided with a vertical loop sufficiently high to prevent water being carried over to the air pump. The air pumps are interconnected to each air chamber.

Venturi meters for measuring the discharge of water from the station and from one main to the other were set by the contractor on each discharge main and on the cross-connecting main. The meters of the discharge main are 24 in. in diameter and on the crossover main 12 in. in diameter. These meters were provided with dial-indicating gauges and also chart recorders, graduated to indicate the flow in gallons per minute and in addition with an integrating meter which registers the total flow in gallons.

The electric current for operating both of these stations is supplied by the New York Edison Company. That company has six generating and distributing stations in the city. Each station has special 3 phase cables laid in ducts running from the main generating station.

There are always hydrants within 400 feet of any building in the district, and there are enough hydrants so that 60 streams of 500 gallons per minute can be concentrated on a block with a length of hose not exceeding 400 to 500 feet.

To save time in sending orders to the engineers at the stations, concerning the pressure and amount of water required, a system of telephone boxes has been installed, so placed that a fire in any part of the district can be watched from at least one of these signal stations.

Test of New York, Borough of Manhattan, High Pressure Fire Service, 20 2-in. Nozzles on 3-in. Hose Lines.

The specifications for the pumping system provided for an endurance test of each motor and pump lasting 24 hours without stop. These tests were conducted by Professor Rollo C. Carpenter of Cornell University, from whose report I will now briefly quote.

> "The delivery every hour was largely in excess of the contract requirement of 15,000 gallons. The smallest delivery for eight consecutive hours occurred at the last part of the test when the average capacity, as shown by readings, was 18,447 gallons per minute and the average efficiency was 72.2%. During this time, the average pressure pumped

against was 314.5 pounds or an excess of about 6 pounds over the contract requirements."

The efficiency guaranteed by the contractor was 71%.

The high pressure fire service system in New York, which was put officially into service on July 6, 1908, has been successfully operated at many fires, but it had a crucial test on July 7, 8, and 9, 1909. when it was brought into service for five simultaneous fires, three of them of more than usual extent and activity, and one particularly so.

The cities of Niagara Falls, N. Y., and Spokane, Wash., are now installing motor driven centrifugal pumping equipments which possess several novel features. In both of these cities, the pumps are so arranged that they discharge directly into the water mains and supply water at domestic pressure. The pumping units are so designed, however, that the pumps may be operated in series. This doubles the domestic pressure and is used for fire fighting purposes.

NIAGARA FALLS, N. Y.

The Niagara Falls equipment consists of six 14-in. 2-stage centrifugal pumps, each directly connected to a 300 H. P., 440 volt, 25 cycle, 3-phase, induction motor. These motors are of the wound rotor type and have a full load speed of about 735 revolutions per minute. Each pump, when running at full load speed of the motor, has a capacity of 4,200 gallons of water per minute with a pressure of 75 pounds per square inch at the discharge nozzle. The pumps will normally operate with a suction lift of about 12 ft. but in extreme cases this will be increased to 20 ft.

By means of suitable piping and valves within the pumping station, three of the pumps can discharge into a receiver, to which is connected the suction of the remaining three pumps. It is in this manner that the fire pressure of 150 pounds per square inch is obtained.

SPOKANE, WASHINGTON,

At Spokane the service rendered by the pumping station is practically the same as at Niagara Falls; the pumping units however, are somewhat differently arranged.

A 900 H. P., 2,200 volt, 60 cycle, 3-phase motor is placed between and directly connected to two 14-in., 2-stage centrifugal pumps. There are three pumping units and each when running at 870 revolutions per minute, will deliver 12,000,000 gallons of water per 24 hours, against a total head of 260 ft. when operated in parallel. When arranged for series operation, each unit will deliver 7,500,000 gallons, against a pressure equivalent to 430 feet head, when running at the same speed.

There are a number of small cities throughout the country where the quantity of water required for fire fighting purposes is small, as, for instance, is the case at Rhinelander, Wis., and Cloquet, Minn. In these cities, small motor driven centrifugal pumps have been installed. These pumps have a capacity of about 750 gallons per minute with a discharge pressure at the pump nozzle of 100 pounds per square inch. Mention is made of these equipments to show that motor driven centrifugal pumping equipments for high pressure fire service systems need not necessarily be confined to a metropolis and to large cities.

I have endeavored to describe a few of the prominent installations of high pressure water service systems for fire protection in the United States. There are, however, a number of others equally worthy of lengthy description but which, owing to the lack of time, must be omitted. I refer to the installations in Brooklyn, N. Y.; Jacksonville, Fla., and Toronto and Winnipeg, Can.

You have here a brief description of a few of the prominent high pressure fire service installations which are now in service, and which are daily demonstrating their ability to perform the work imposed. A point in regard to these installations which is of the greatest moment to our merchants and manufacturers has not been mentioned, but it should here receive very serious consideration. It is the tendency which installations of this character have toward reducing insurance rates. There has been prepared, by the Committee on Auxiliary High Pressure Fire Protection for the City of Hartford, Conn., a large amount of valuable information in regard to this matter, and published in a report to the Court of Common Council under date of March

City	Source of Power	Total Capa'y Gallons per Minute	Total Cost of Installation	Effect on Insurance Rates
Buffalo	3 Fire Boats			Reduction of 30 cents per $1000
Chicago (Proposed)	1 Station	30,000	$3,203,480	25% Assumed
Cleveland	2 Fire Boats	10,000	$170,000	Reduction of 80 cents per $1000 proposed
Coney Island	1 Station	3,600	$90,000	Reduction of 25%
Detroit	2 Fire Boats	10,000		Probably has prevented an increase
Millwaukee	3 Fire Boats			Reduction of 10%
Philadelphia	1 Station	15,000	$700,000	Penalty of 25% removed
New York	2 Stations	30,000	$3,950,400	
Newark	Gravity	3,500	$135,000	Reduction of 10%
Providence	Gravity	3,472	$143,136	No change

5, 1907, from which I have taken the preceding table for your information. Also, I have, from authentic source, a statement made by the president of one of the large Mutual fire insurance companies, in which he offers, after a careful examination of the Manhattan system, to accept additional insurance to the extent of $1,000,000 on property in the protected territory, which risk could not previously be accepted.

I have also attempted to explain to you the great advantages which are obtainable by means of installations of this character but, in conclusion, there is just one more important point, which should be drawn to your attention and that is, a strong, although perhaps not altogether sufficient, reason for the installation of a safe, modern and efficient fire extinguishing system, is the beneficial influence such additional protection will have on outside capital.

Discussion

President Alvord: We are all indebted to the author for his very clear presentation of this paper. The use of centrifugal pumping units, not only in high-pressure fire-service but in water-supply where the cost of power is, for various reasons, permissible, is increasing. The Niagara plant which he mentions is of course based on the low water-power cost, which makes it possible to use a pumping unit of this kind. I believe the cost of power to the station which he describes is at a contract rate of $9.00 per H. P. per annum. With interest on line equipment, the cost is brought up to about $12.00 at the switchboard,—a very low power-cost. The Spokane installation doubtless has a similarly low cost for power.

George M. Mayer, M. W. S. E.: Are the impellers of steel or cast iron?

Mr. Sando: The impellers are of bronze, but the casing is of cast iron.

Albert Scheible, M. W. S. E.: Mr. Sando spoke of the low efficiency of the pumps. I would like to know what it is.

Mr Sando: The 72% is the efficiency of the pump. The efficiency of the motor is about 93%. That will reduce the combined efficiency of the unit to about 67% on the combined machine. Centrifugal pump efficiencies vary considerably with the service against which the pump operates. For instance, large single-stage pumps which operate against comparatively low heads, similar to the ones which are now in use at the 39th street pumping station in this city, have what might be termed higher efficiency. The combined efficiency of those engine-driven units, if I remember correctly, is approximately 80%. As the quantity decreases and the head increases, the efficiency is somewhat affected.

However, motor-driven centrifugal pumping units which are used for fire protection service are called upon to operate intermittently, and, as stated, the service which they render must be of such a nature that they can always be ready for operation. Consequently the efficiency is a feature that is not generally considered or given any very serious thought.

Mr. Scheible: Mr. Sando quoted from a letter from Chief Croker, I think, as to the saving in the insurance in New York City. May I ask if that was based on this same investment that is referred to in the table on the last page of his paper, where the cost of installation is given as nearly $4,000,000.

Mr. Sando: The cost of the New York high pressure installation was approximately $4,000,000; to be exact, $3,950,400. The saving in premiums due to the reduction in insurance on account of the successful tests of the New York high-pressure fire-service installations amounted to $500,000. The figure of $750,000 covers the Brooklyn installation as well. Unfortunately I have not at hand at the present time the initial cost of the Brooklyn installation. I should imagine, though, it was in the vicinity of $2,000,000, or probably just about half the amount that was spent in New York City.

President Alvord: About what length of time does it take to get up fire pressure in such a system as that installed in Milwaukee, where the fire-boat service is relied upon to connect with the system and put up the pressure? I suppose the pressure is on continuously in such a system as that, to some degree.

Mr. Sando: A fire-boat is supposed to be at its moorings, but frequently it is necessary to take it away for some purpose or other. If a fire should occur while the fire-boat is not at its proper mooring, there may be considerable delay. If it is at its mooring, and the fire is at the extreme end of the zone which is protected by the high-pressure mains, then also some time will be required. Of course, if the mooring is close to the source of the fire, it will be but a short time. That is a difficult question to answer and in fact it cannot be satisfactorily answered, for the matter depends entirely upon the conditions. Some cities are so situated that it is necessary to drain these pipe systems to prevent damage due to freezing, and in that case more time is necessary to fill the pipes and to have the water supply at the seat of the fire.

H. S. Baker, M. W. S. E.: In South Chicago there is a separate fire pipe laid for the fire-boat service along Ninety-second street as far as Commercial avenue and another one down from the river three or four blocks east and west. Will that do away with the steam fire engines?

Mr. Sando: I cannot state that fire engines are no longer used in New York in that protected area which is known as the drygoods district, but I have reason to believe that they are run only in case of a fifth or sixth alarm of fire. For the first and second alarms they are not used at all, but just where the division is I am unable to state.

Mr. Mayer: The paper, in describing the Baltimore equipment, states that there are large air chambers and separate air compressors for the air chambers. I would like to inquire whether there are any automatic devices to assist in regulating them.

Mr. Sando: No, automatic devices are not used. The air is supplied under a pressure of approximately 300 pounds and after the chamber is charged it takes care of itself automatically. The idea of that air chamber is to act as a cushion to the water and prevent serious damage due to the water hammer. The air, of course, must be replenished to make up the losses due to absorption by the water, but the pressure in the chamber is a fluctuating amount regulated by the pressure against which the pump is operated. The pressure must be just enough in that chamber to preserve an air pocket so that the water will not completely fill the chamber.

Chas. B. Burdick, M. W. S. E. (by letter): It has been well worth while to record, as the author has done, the principal features of the high-pressure fire-service plants recently constructed in our large cities. Although the subject has only lately been taken up by the larger municipalities, fire service directly from the city hydrants is by no means a new problem, and high-pressure fire systems, such as have been described in this paper, are the outgrowth of the experience of the smaller cities in the same matter, accomplished in a different way.

In most cities of 100,000 to 200,000 population, or less, water is furnished at the public fire-hydrants under the pressure needed for fire purposes. In probably the majority of cities whose population exceeds the above figures, it has been and is customary to use steam fire-engines, drawing their supply from the city distribution mains. This system is expensive, and there are other obvious reasons why it is undesirable under the congested conditions of great cities. In cities of from 10,000 to 20,000 population, the maximum water-rate demanded for fire protection is about double the domestic water-consumption rate, and the waterworks systems, including pumping machinery and distribution mains, are designed upon the basis of the water rates demanded in fighting fire. In these cities it is the custom, upon an alarm of fire, to raise the domestic pressure to such amount as is necessary, depending upon the nature of the buildings and the topography of the city, reducing the pressure as soon as the need for it has passed. This is practicable, because an alarm of fire is comparatively infrequent.

Under a moderate rate of domestic water-consumption, say 100 gallons per capita, the water rate demanded for fire service and for domestic service will be about equal in cities of 100,000 population. In cities of 300,000 population, the maximum fire rate will be about half the domestic rate, and the ratio grows less as the population increases until the condition is reached in a dozen or more of our largest cities, where the water rate demanded by even a large fire is of small importance compared to the ordinary demand of the city. In these cities, the design of the water-distribution system is based almost entirely upon the needs of the domestic consumers. As the cities increase in population, however, the fire alarm becomes more frequent, and the necessity for raising the fire pressure becomes more frequent and burdensome. To furnish fire pressure from the city water-works mains in Chicago, would practically mean that the station must operate under fire pressure at all times. If practicable at all, it would increase the operating expenses and fixed charges on the water-works to a figure greatly disproportionate to the resulting benefits.

It is for these reasons that the system of fire protection in the smaller cities becomes impracticable in those of larger size, thus naturally the large cities are led to accomplish that which is done directly and easily in the small places, by the installation, in the districts containing the greatest fire risks, of the so-called "high pressure fire systems," separate and distinct from the water-supply for domestic use.

The problems involved in these plants are of the same nature as those in the ordinary water-supply. The application of these principles, however, leads to designs widely different from those of the ordinary water works pumping and distribution systems. The operating expense of the high pressure system is principally a "stand-by" expense, aggregate hours of operation being comparatively small. The fixed charge is the more important debit against the investment. For this reason, machinery of low duty is proper.

The choice of the motive power introduces some very interesting problems, as is evident from the widely varying designs described by the author of this paper. In this respect the internal-combustion engine has the important advantage that it consumes fuel only when in operation, but, as would be expected, it suffers somewhat in the rather complicated mechanism necessary for its prompt use. Power directly from steam requires the constant losses incident to the maintenance of steam pressure in the boilers, which must always be subject to instant use at their full rating. The installation in San Francisco described by the author, involving steam boilers, is probably advisable chiefly because oil is used for fuel, doubtless permitting the "stand-by" service to be more economically accomplished than would be practicable with coal involving fixed grate areas and low evaporative economy when the boilers are not in active service. If coal gas could be more directly applied to pumping, it would be an ideal source of power in the great cities, for in these places the gas-distribution mains and the storage facilities are large.

It has been stated in the paper that electricity is an ideal power for high-pressure fire protection. This is true, particularly in the direct application of the power. Any system, however, is no stronger than its weakest link, and the weak link in electric power for this purpose is the means for delivering power to the pumping station. In the largest cities, such as New York and Chicago, great precaution is taken to provide against power shut-downs, the electric distribution systems being usually fed from a number of plants, and it would doubtless be practicable, by duplicate feeders above ground and below, to minimize the danger of interruption of service, the consequences of which must be obvious in the matter of fire fighting. These facilities, however, generally exist in only the largest cities, and it is probably in these cities only that attractive figures for electric power could be secured, for although the use of current is small in the aggregate, it must command a high unit price on account of the readiness to serve considerable amounts of power.

It is obvious, where it is practicable to secure water that can be delivered to the district by gravity at a reasonable expense, that such a system has its advantages. Situations, as in San Francisco, where water can be pumped at a relatively low rate to an elevated reservoir, and furnished from the reservoir at any rate desired, are obviously advantageous, but such systems are only practicable in cities of very broken topography, and the question, even where a gravity supply is practicable—the service being equal—is a matter of the proper balance between the fixed charges on the investments involved and the operating expense of the plants. A direct-pressure system can be made practically as reliable as a gravity supply by the proper utilization of duplicate parts.

The water pressures involved are principally dependent upon the nature of the property to be protected, and the height, or the probable future height, of the buildings, but the pressure is also governed by the economical friction-limit in the distribution pipes. In general, it is probable that considerably higher friction losses are warranted in the high-pressure distribution-pipes than is the case in city water distribution systems. As in the selection of the motive power, there is here a nice balance between the fixed charges in distribution pipes and machinery.

WIND LOADS ON MILL BUILDING BENTS.

Albert Smith, M. W. S. E.*

Presented November 9, 1910.

Wind-pressures on mill buildings are handled by designers by various methods of distribution and application. Among the most common may be mentioned:

(a) No wind-panel loads are placed on the roof, the assumption being made that the wind will blow the snow off the roof and that the wind stress will not be greater in any member than the snow-load stress that it displaces. The column is designed for the maximum bending moment in the windward column, due to the wind reaction and a uniform wind load over its length.

(b) Horizontal panel loads from wind are placed both at the column panel-points and at the panel-points of the windward truss to get reactions and the stresses in the roof truss.

(c) Normal panel-loads whose amounts are derived from the assumed horizontal pressure by empirical formulae, are placed on the panel-points of the truss and horizontal panel-loads on the column.

In all these cases, for fixed-end columns, the point of contraflexure in the columns is assumed to lie half way between the base and the foot of the knee-brace—an assumption borrowed from the well known proposition for a braced bent with a single horizontal load at the top.

The most evident objection that may be urged against the first method is that it leaves out of account a possible reversal of stress in some of the members of the roof truss.

The second and third methods give knee-brace and column sections so large that many designers soften off the assumed wind-pressure as applied to these members, and thus get what they regard as an economical, as well as safe, design. A great many structures have resisted wind effects for many years whose stresses, if figured by the method of either (a), (b) or (c), would seem to predict failure either in knee-brace connection or in column section.

So far as I have been able to learn, attention was first called to negative pressures, or suctions, on parts of the surface of buildings by Mr. J. O. V. Irmiger, of Copenhagen, whose experiments are reported in *Engineering* (December 27, 1895). In these experiments Mr. Irmiger found that the suction on the leeward surface of a thin plate generally exceeds the pressure on the windward side, and that on the solid model of a building the suction on the leeward roof far exceeded the normal pressure on the windward roof. These experiments, while acknowledged to be of great interest, failed in producing any change in the assumptions for wind-

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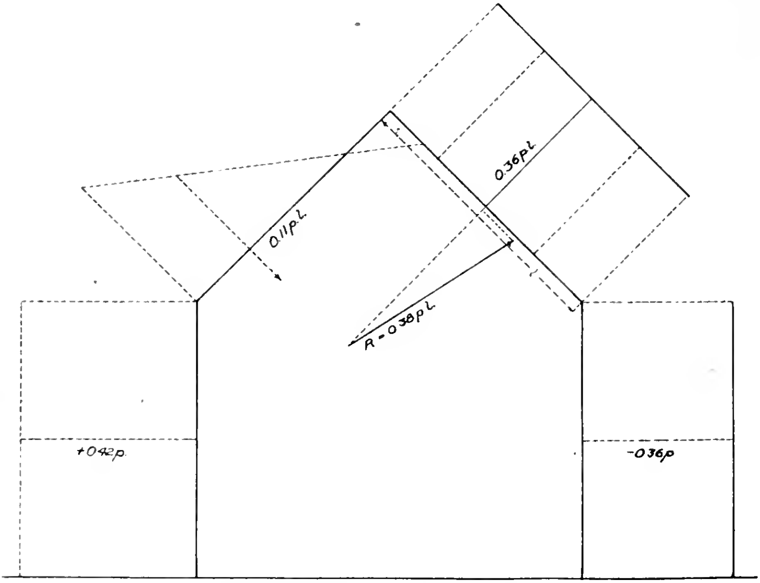
loading on buildings because of the small size of the models on which the tests were made, and on account of the discrepancy between the 57% suction on thin plates found by Mr. Irmiger and the 33% found by Mr. Dines—another investigator in the same field.

In the hope of reconciling these differences and deriving data for accurate distribution of the wind-loads on buildings, Dr. T. E. Stanton, of the British National Physical Laboratory, in a series of tests on wind-pressure on structures, included a very exhaustive examination of the pressures on a model of a building. This model was much larger than that of Irmiger, and the experiments were performed in the open air instead of in an artificial air current. The results indicated a considerable suction on the leeward roof and wall, but were far from checking with those of Irmiger.



p = normal pressure on thin flat plate.
l = length of bay
Velocity of Wind - 20 to 34 miles per hour.

IRMIGER'S EXPERIMENTS ON SOLID MODEL.
FIG. 1.

The most significant part of the results of Stanton's work as given before the Institution of Civil Engineers, December 3, 1907, seems to the writer to be the experiments on the air-pressure on the *inside* of the building.

The maximum effect of the suction must be 14.7 lb. per sq. in., and it seems rather more than probable that the increase of suction is not parallel to the increase of pressure. All the experiments so far performed have been in air currents of moderate velocity. It is to be expected that for velocities of 80 to 100 miles per hour—some four times those of Irmiger's and Stanton's air-currents—the ratio of suction to total wind effect would very greatly diminish.

RESULT OF OBSERVATIONS ON MODEL IN ARTIFICIAL CURRENT, TO DETERMINE THE EFFECT OF OPENINGS EQUAL TO 4 PER CENT OF EXPOSED SURFACE, IN PRESSURE ON INSIDE OF BUILDING.

ANGLE OF ROOF	STATE OF OPENINGS		Ratio of Intensity of Pressure Inside Model Building to Maximum Intensity on the Windward Side of a Plate on which the Wind Impinges Normally
	WINDWARD SIDE	LEEWARD SIDE	
60°	Open	Closed	1.00
60°	"	Half-open	0.67
60°	"	Open	0.20
30°	"	Closed	0.82
30°	"	Half-open	0.49
30°	"	Open	0.20

Another objection to making use of the results of Stanton in the design of mill buildings arises from the location of the model during the tests. The models were mounted on a framework 50 feet high, in order to escape the disturbing effect of obstacles in the wind-current just ahead of the exposure. The conditions of a mill building resting on the ground are quite different, and the shutting off of the current of air below the body tested should produce large changes in both the leeward suction effect and in the inside pressure. The writer is therefore of the opinion that the results of Stanton as shown in the table, while indicative of the manner of distribution of the wind force, do not furnish a basis for calculating the ratios of the distribution.

RESULTS OF OBSERVATIONS WITH MODEL ARRANGED AS IN FIGURES 2 AND 3.

Inclination of Roof to Horizontal.	Resultant Pressures in lb. per sq. ft. of Leeward Surface at 20 Miles per Hour, Wind Velocity.
64°	0.36
48°	0.68
36°	0.82

For a long building, without open ventilators in the monitor, in the light of the experiments I have quoted, it is evident that there exists a considerable suction on the lee roof and wall, which

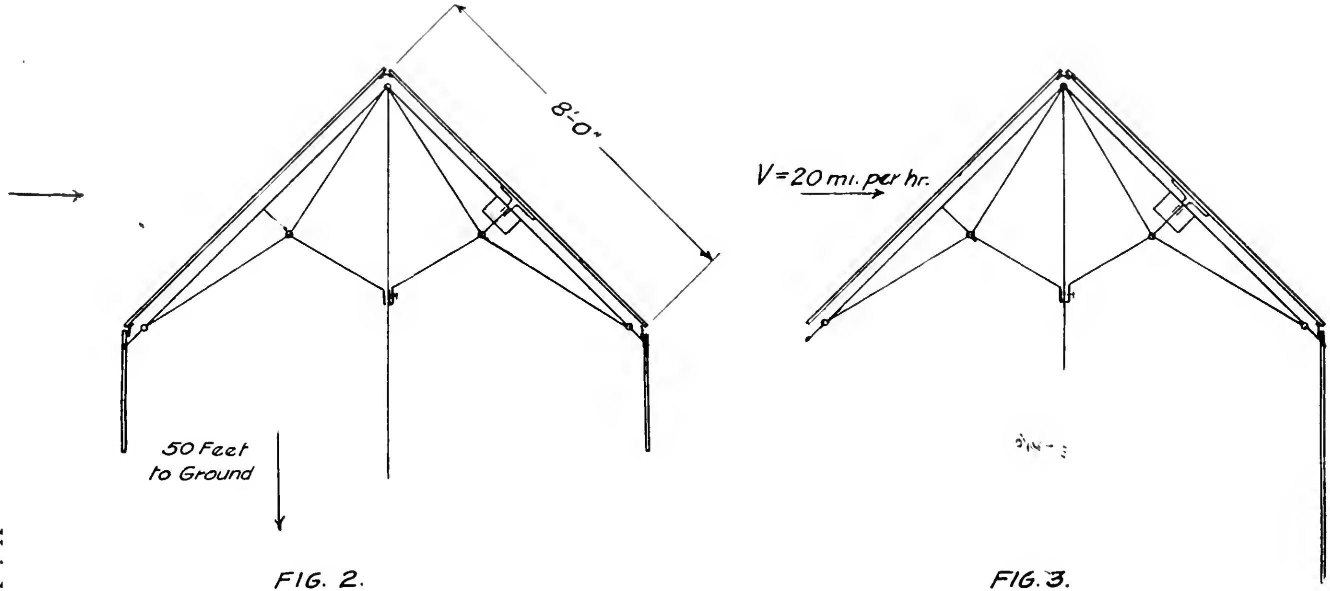


FIG. 2. FIG. 3.

MODEL USED IN STANTON'S OPEN AIR EXPERIMENTS.

for a wind of 80 miles an hour I should assume to lie between 6 and 8 lb. per sq. ft.

If this building were air tight in its walls and roof, assuming the total wind effect 20 lb. per sq. ft., the panel loads on the leeward roof and wall would be derived from the suction, and the pressure on the windward roof and wall would be derived from the difference between 20 lb. and the suction.

The only case in which all the loads could be concentrated on the windward roof and wall, as is now generally done, is that where there is no leeward roof or wall.

In most buildings the openings are approximately the same in amount on the two sides, and the error from assuming them exactly equal should be small. If the openings on either side of the building can be assumed equal, when a steady wind is blowing, the discharge of air on the leeward side must be equal to the intake on the windward side. But this implies an equal difference between the inside and outside pressures on the two sides of the building. That is, the *pressure on the inside of a mill building is a mean between the windward pressure and the leeward suction.*

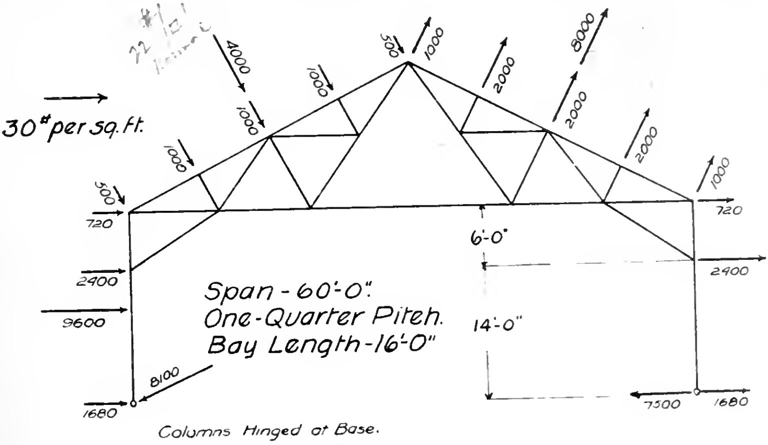


FIG. 4.

In Fig. 4 is shown the loadings at the various panel points of a bent of 20 ft. bays, for a total wind effect of 30 lb. and a suction of 8 lb. It will be noted that the only panel loads which are affected in amount by the assumed size of the suction are the normal inward pressures on the windward roof.

The suction is taken as the same on roof and wall, while the windward roof-pressure is derived from the well known formula of Duchemin. An error in the amount of the suction makes an exceedingly small error in the amount of panel loads.

In Fig. 5 is shown the loads and stresses for a mill-building bent of the same dimensions computed by the methods given in

Ketchums *Mill Buildings.* The wind has been taken as 30 lb. per sq. ft.

In Fig. 6 is shown the stresses in the same bent from the same total wind-pressure, computed by the method proposed by the writer.

It will be noted that the maximum stress in the knee-brace is much less by this proposed method, and that the compression stresses in some of the interior diagonals of the truss which are in tension under dead loads are sufficiently larger to cause reversal of stresses in many cases. If the assumptions are even approximately correct, it is evident that the factor of safety of many roofs designed for small snow and dead loads is much smaller than the designer intended.

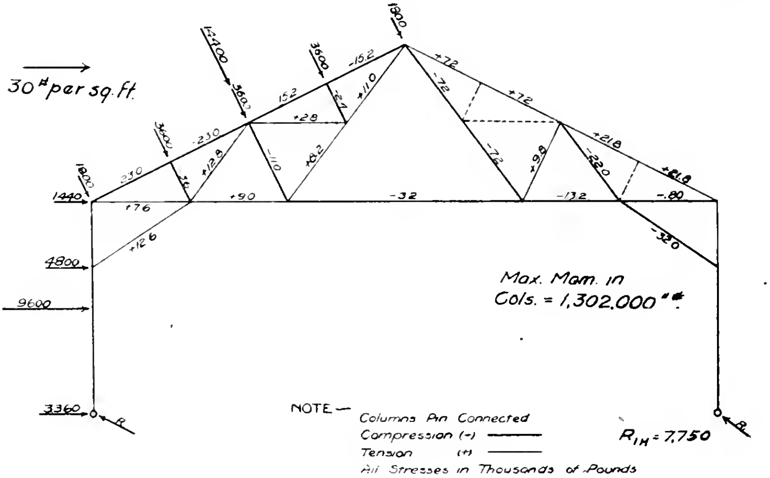


FIG. 5.

In regard to the proposition that there is a very considerable wind-pressure on the inside of buildings exposed to high wind, which pressure gives a resultant upward pull on the roof, it is a matter of common-knowledge that roofs blow off, but not in; that in a tornado or hurricane whole structures are lifted bodily and are carried considerable distances. Mr. T. Nielsen mentions in *Engineering* (October 9, 1903), a roof of a long building which was carried a distance of 100 feet by the wind. On examination it was found that the rafters of the lee side were bent outward. In regions much affected by high winds the natives have developed methods of weighting down the roof to overcome the uplift. The St. Louis tornado also furnished examples.

In the stresses in columns, it appears that a very considerable part of the maximum moment in them is due to the uniform load of wind, as shown in Fig. 7. A reduction in the amount of this uniform load, from assuming one-half of it to act on the lee column, would cause a material reduction in the maximum moment. I think most designers of mill buildings feel that a rigorous application of the more common assumptions in text-books gives column sections that

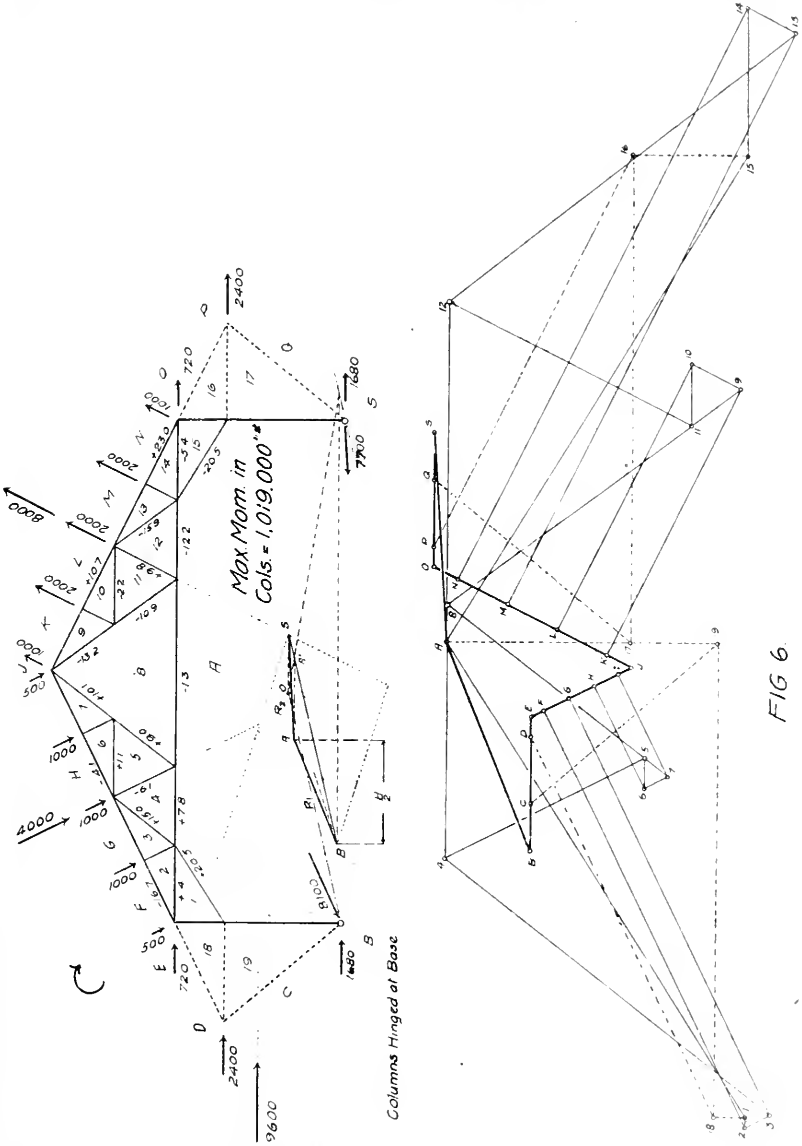


FIG 6.

are unreasonably large. Many of them have adopted assumptions that give results which they regard as reasonable, some of which assumptions are utterly indefensible on mechanical principles.

The weakest point in our present assumptions in regard to mill-building stresses, apart from the question of where the loads are to be applied, is in the assumption that the point of contraflexure for fixed-end columns lies half way between the base and the knee-brace. A formula could, however, be written by the method of least work, which would give the point of contraflexure almost exactly. Such a formula would be very awkward of application for uniform loads on one side of the bent only, giving points of contraflexure at different heights on the two columns. Under the writer's assumption, however, the points of contraflexure would lie at the same heights, and the formula would involve no increase of labor in calculation of stresses when rigidly applied. A table of results for bents of various dimensions would enable the designer to approximate very closely to the correct position for the point, after which the labor would be just the same as that now required.

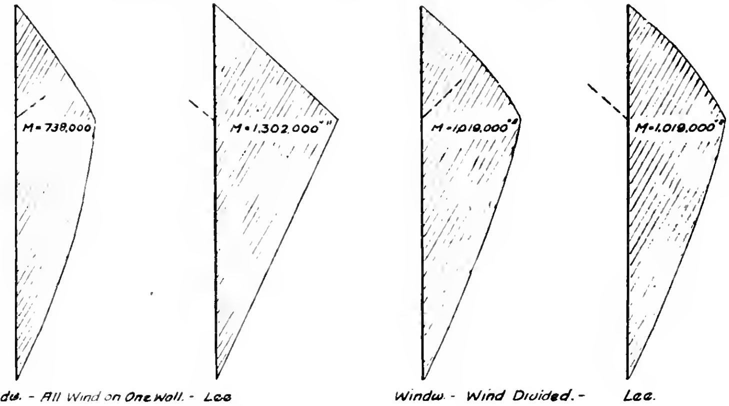

M = 738,000
M = 1,302,000"
M = 1,019,000"
M = 1,019,000"
Windw. - All Wind on One Wall. - Lee
Windw. - Wind Divided. - Lee.

FIG. 7.

The most striking change in the size of sections caused by the use of the writer's assumptions comes in the girts. The bending moment in all girts and hangers is cut in two if we assume the wind effect to be equally divided between the two walls.

Whatever doubt may exist as to whether we ever get the wind-pressure we assume on a bent as a whole, there can, I think, be little doubt that the small area carried by a single girt is certain to be called on to resist at times more than our assumed load. Nevertheless, there are many cases of single angle girts in buildings with good exposure which have successfully endured their wind-loads, although the wind-load ordinarily assumed would stress them beyond the elastic limit of the material. It has been urged, as explaining the endurance of such girts that they act as a string, after a certain amount of deflection has taken place, but—as Mr. Paul Stewart, of the Illinois Steel Company, pointed out to the writer—if this string-action is of such amount as to appreciably relieve the stress in the girt, the connection rivets of the girt would have to take a horizontal pull for which they are quite inadequate.

A point of some difficulty arises in connection with buildings having open monitors. In such a case the pressure within the building is somewhat reduced. Where the size of the stream of air passing through the louvres is large in comparison to the size of the building, it is probable that even with the slowing of its movement caused by the inclination of the louvres, it will retain enough velocity to diminish the inside pressure.

The diminishing of the average pressure on the inside of the building is due to the velocity-head of the body of air on the inside as a whole, and only in exceptional cases would this be important. Loads on the louvres might be computed separately, but these could not be regarded as single flat plates under the total wind, both on account of the pressure behind, and because the effect of the interference of the adjacent slats is an unknown and probably an unknowable factor.

A very important application of the method discussed here is in three hinge arches for drill halls and auditoriums. The reversal of stress which takes place in the leeward trusses would be very likely to cause failure.

In train-sheds, since one end will be open to the wind, the largest wind-stress on the truss members may be found when the wind is quartering on the open end of the structure. Here the inside pressure is a function of the angle of inclination of the wind with respect to the end plane of the building and the amount of the normal pressure. The normal pressure on surfaces inclined at 45° has been determined as equal to the pressure on a normal surface, and we should have, for the wind thus directed, the same panel-loads on the windward side as for the wind normal to the length of the shed *on the vertical* portions of the roof, but diminishing more rapidly toward the peak. These panel-loads are counteracted by loads due to the inside pressure, giving resultant panel-loads which increase from zero on the vertical surfaces to an outward pressure at the peak, equal to the total wind effect. On the leeward side, all panel-loads are outward and equal to the full amount of the normal wind-pressure on the area.

Where the vertical wall is high, such loading would give very high compressive stresses on the bottom chord of the leeward truss.

For train-sheds with open sides, for which Stanton's experiments furnish an almost exact parallel, the usual method of considering pressure on the windward side only seems to be justified. It should be remembered, however, that Stanton's model was placed 50 feet from the ground, and that for an opening below the lower edge of the roof, which is less than the height of the enclosed roof, the results might be, and probably would be, very different.

The making of accurate tests on the effect of the wind is a very difficult matter in itself. When such tests are made in any given location, the results must be applied with many reservations, since they *are strongly colored* by the character of the exposure. If one watches the changing eddies of a stream of water whose bed is only slightly irregular, he gets an idea of the manner in which the intensity of the wind-pressure may vary, not only between two different locations, but at different times in the same location. The influence of surrounding objects is very difficult to determine. While it is known that the presence of adjacent surfaces may considerably increase the wind-pressure on any body, we cannot say what the effect would be of any given arrangement of adjacent buildings. It is quite possible that in a series of buildings arranged in the form of a funnel we should have an increase of the wind-pressure at the point from action similar to that which makes the tides especially high at the end of a deep bay.

The specification of 20 lb. per sq. ft. of wind-pressure, being the effect of a wind of about 80 miles an hour velocity, seems to me to be quite safe for mill buildings in most cases. Indeed, there are many cases in which it might safely be reduced—places where the velocity at the surface of the earth is certain to be less than that at the heights at which velocity readings are taken. But there are also positions in which the exposure is so unfavorable for the building that it would be only prudent to increase *the assumed pressure.*

In conclusion, the writer advocates:

First, placing the wind loads equally on the two walls, and inward and outward on the windward and leeward roofs respectively, as giving important changes of stress in members of the roof-truss, as giving less stress in the knee-braces and columns, and as permitting the rational design of the girts.

Second, an accurate determination of the point of contraflexure for fixed-end columns.

Third, making the amount of the wind-pressure for a given building a matter to be decided in the light of the exposure of that building.

If some, while admitting the general truth of the premises of these points, object because they involve an increase in the labor of the engineer, I would urge that a ton of steel will pay for many hours of engineering labor.

Discussion.

Professor Smith, M. W. S. E.: The whole question of wind pressures and how they act is still in so chaotic a condition that it is very difficult and rather embarrassing to propose a change in the applied loads, because there is no assumption that one can make that he can view as exactly correct. Nielsen, of Copenhagen, adopted Irmiger's experiments as actually showing how the loads should be applied. He published in *Engineering* a careful analysis of a truss with a monitor and louvres, but it seems to me that the whole analysis was absurd, because it was based on Irmiger's experiments in a closed channel on small models. and I think it is true that no one can say that such and such coefficients should be used on certain parts of a structure or for different types of structures. But the proposition that there is an internal pressure in a building which is approximately a mean between the suction on the leeward side and the pressure on the windward side, seems to me to strike very near to the truth. The experiments quoted in the table by Stanton refer simply to Stanton's model experiments. I have checked back his experiments for openings on the windward side and the leeward side also, with his results in the other series of experiments, and this 20% is almost an exact mean between the leeward suction and the windward pressure.

If we could say that mill buildings as ordinarily made have equal openings on both sides, I think the proposed loading would be without opposition. As a matter of fact, of course, we cannot; yet it is true that if there is some disparity between the openings on the windward and leeward side the condition of the windward wall will still be much better than that from the present assumption. The present assumption is really that there is no leeward wall at all and no leeward roof slope; that all the pressure and suction are piled on this windward wall. For the general statement that there is a suction which exerts a very noticeable effect on the lee walls of buildings there is sufficient confirmation, as has doubtless been noted in checking up my references. That matter has been three times discussed before the Institution of Civil Engineers and the general proposition admitted. This, so far as I know, is the first time the proposition has been made, however, that the wind loads should be reduced in accordance with that fact.

F. E. Davidson, M. W. S. E.: It seems to me that the third conclusion of Professor Smith is a very important one and one that should be given a great deal of thought. As a matter of fact, I do not recall in my limited experience in connection with mill buildings a single instance where the exposure on both sides of the building was the same. I do not recall a single case, with the exception of one or two gas houses, where there were not other things to be considered in designing the columns than the wind loads themselves. Usually we have a lean-to truss, probably a jib crane on the column section with a traveling crane, and there are many things to be considered in designing columns aside from the wind loads alone. I think that every engineer, in designing or considering wind loads on mill buildings, should make a careful study of the actual conditions surrounding the location of the building. The presence of other buildings, the topography of the ground, and the general exposure should be carefully considered. In most localities,—in the city, at least,—if we are to design a new mill building in a manufacturing plant there are other buildings in close proximity to the new building. Personally I have even disregarded the effect of wind on, say, the first 20 or 30 ft. of the side of the building, and only considered wind pressure on the upper third or upper fourth, as the case may be, disregarding the wind entirely on the lower portion of the side of the building on account of the protection it receives from other buildings in close proximity to it. All those questions must be given careful consideration before we make our assumptions for loading. I think that conclusion of Professor Smith's is well brought out and can not be given too much consideration by engineers in designing mill buildings.

S. T. Smetters, M. W. S. E.: In designing mill buildings we find it most difficult to design the frame for the gable end. The girts and framing at the end of the mill building are the most severely strained of any of the structural frame.

A mill building of 75-ft. span will require comparatively light columns to carry the actual live and dead loads that may come upon it. The structural framework at the end of the building has very light actual dead or live load to carry, and the theoretical load, or occasional load, may be many times the actual load that the structure will ever be called upon to carry. In designing the framing for the end of building, in order to be economical, one generally omits the gable truss, using only a light frame and columns, which support the girts and form the enclosure for the building. In the end construction, the light columns act as girders supported horizontally at the foundation and at the line of the bottom chord, or roof purlins. The reaction at the foundation is easily taken care of, but at the top of the column it is more difficult. If the same unit value and assumption are used to design this portion of the building, as for the trusses, columns, etc., the weight of material will become excessive and perhaps, in reality, a waste. As a risk from complete failure is small, and as if the same should happen no serious results would follow, it would be good engineering to design this portion of the building using much higher unit values.

The wind load on the end of the building may be very severe in either direction from direct pressure, tending to force the ends inward, or suction tending to pull the ends outward. Both of these loadings should be considered in the design.

I remember distinctly one case of a mill building at Indiana Harbor, where, before the building was occupied and after construction was completed, a portion of the corrugated iron covering had to be removed to reduce the pressure from suction of the wind on the end of the building. The girts appeared out of line 6 or 8 in., but as soon as two or three sheets of corrugated iron were removed, the end of the building came back to proper line.

The columns at the end of the building were 8 in. I beams 42 ft. long and about 14 ft. centers; the girts were $3\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{5}{16}$ in. angles about 2 ft. 9 in. centers. The tops of these columns were properly braced at the line of the bottom chord of the truss. The far end of the building was enclosed, so that bears out the assumption that there is a considerable load produced from the suction of the wind.

This last summer the idea of a wind exerting a force in the opposite direction to which the wind was blowing was brought to my attention very forcibly from the fact of three trees that stood in the avenue, two of which went down in the opposite direction to which the wind was blowing; the other, which was in the immediate path of the wind between two buildings, stood up. The two trees which fell apparently towards the direction of the wind, were just off that path, showing that the wind must have started to whirl as it went by the building. We think that the same thing happens to wind blowing around a tall mill building. It has a tendency to push in the end windows on the leeward as well as on the windward end, which has happened to some of the Illinois Steel Company's buildings at the South Works, South Chicago.

W. C. Armstrong, M. W. S. E. (Chairman): It is reasonable to suppose that there would be eddy currents in the wind the same as there are in streams of water. In fact, we know this to be the case in violent tornadoes or cyclones. Any one who has visited the wrecks of storms of this character has seen a number of these curious phenomena. I remember seeing at one time the entire end of a building drawn out—the gable end—while the rest of the building remained standing. The gable end seemed to be drawn out and lay flat on the ground. Of course, that same effect occurs to a smaller degree with light winds, and it is an effect that undoubtedly should be taken account of in designing such structures.

A. O. Walker, M. W. S. E.: I would ask Professor Smith's method for figuring moments in columns where the column is of varying section, that is, stepped off at the girder, at the crane girders, even.

Professor Smith: The maximum moment occurs at the foot of the knee brace and would be due to the moment of the horizontal component of the reaction minus the moment and the intervening uniform load. This maximum would not be affected by the varying section of the column.

I understand that Mr. Geo. N. Linday, of the American Bridge Company, is engaged in some calculations on the exact location of the point of contraflexure in fixed columns, and I hope something will be presented to the Society along this line. Doubtless the present assumption that it is half way up, which is founded on the general proposition for braced bents, is far from true. It is quite evident that a uniform load on the side of that wall will cause a displacement of this point of contraflexure, and the effect will be quite different from the effect of a single load placed at the top. That itself is, of course, not exactly accurate for the single load. It is to be hoped that we can make some closer approximation. It is possible that busy men designing a great many trusses in the course of a day may view with alarm the proposition to use the method of least work in determining the location of the point of contraflexure, but it is perfectly feasible to make a table. That, as I understand it, is Mr. Linday's proposition, to make a series of formulæ and to make a table from which one can locate, in a given case, almost exactly the point of contraflexure, without any calculation whatever. If I may intrude on the time of the Society with something not germane to Mr. Walker's question, I will say that the method I have proposed makes it feasible to use an exact point of contraflexure. So long as all the pressure is taken on the windward side of the building, any displacement of the point of contraflexure due to a uniform load against it will affect only the windward column, and we have the case of a different height of point of contraflexure on the windward side than on the leeward side,—a case which would be extremely difficult of solution,—whereas if the pressure be divided equally between the two walls, we can make an exact determination of the point of contraflexure and provide for it very simply, as the case differs not at all from the present assumption.

Mr Davidson: I would like to ask Professor Smith if, in his opinion, we can ever assume with safety a uniform load on the side of the building. In other words, is it not a fact that owing to the friction between the air and the earth itself, even if we assume a mill building sitting out on the prairie with no trees or no shrubbery, nothing in the way, is it not a fact that the pressure, say at the foot of the truss, the bottom chord of the truss, will be very much greater than it will at the base of the column, in other words, that the load is a variable load? It is not a uniform load. It may be nothing at the foot of the column and then increase up to 20 lb. somewhere about the top of your truss or top of your column. We are working on the assumption that that is a uniform load, when the actual conditions are that the load is not uniform and under actual conditions can not be a uniform load, nor can it be assumed as a uniform load.

Professor Smith: I agree with Mr. Davidson's proposition. Doubtless the velocity of the air near the earth is much less than that at the eaves of the building; but at the eaves of the building it is retarded almost as absolutely as at the base; that is to say, there is a piling up of the air, making a volume of air that is practically stationary, around which the current of incoming air is deflected, and it seems as though the pressure should not be materially reduced at the bottom from what it is at the top. The pressures on small models have indicated a practically uniform pressure; that is, there is a slight diminution at the bottom due to the fact that the air is retarded. The velocity of impact is less, but it is nearly the same at all points on the side of the building on those model tests. How far we can rely on those tests I am not prepared to say. It is quite different working in a smooth channel from working in a channel where there are trees and other objects sticking up. In the place of trees in the actual case, we might put straws or nails in our experimental channel. I think it would be much safer to assume a uniform load all the way up than to regard it in most cases as zero at the bottom, although I agree with you that where there is a near-by building it would only be sensible to make a reduction of the pressure.

Mr. Davidson: My point in bringing that out was the conclusion of Professor Smith's paper, in which he urges that a ton of steel will pay for many hours of engineering labor. I agree with the Professor absolutely that we have a safer structure if we design a uniform load; but we are designing a building with a good many thousand tons of steel in it. A little difference in the assumption is going to make a difference of a good many tons of steel in the structure, and would it not be safe to make the assumption that the load is not uniform and thereby cheapen the cost of the building without going beyond the point of safety?

C. K. Mohler, M. W. S. E.: I doubt if there is any real justification in assuming that the wind pressure at the bottom of a building will be any less than it is at the top, on account of the decreased velocity near the surface. While the air particles will have a greater striking force at the higher elevation, they will be much freer to deflect and pass around the top and sides. At the bottom the deflection cannot take place downward. Little or no deflection can take place upward on account of the greater striking velocity of the higher currents. Relief, therefore, can be had only by side deflection around the building.

The readiness with which a fluid such as compressed air will adjust itself to an equilibrium, and especially under comparatively slight pressure, and free to flow, in at least three and possibly four directions, as in the higher elevations, which it would be in this case, would result in very little actual difference in pressure. In other words, we would have the slower moving air currents at the bottom of the building brought into a practical pocket. The effect of a pocket in taking up wind pressure is very readily seen in the velocity recorders of the Weather Bureau. With the same area of projection of face and back exposed to the wind, the concave side takes up and converts so much of the wind velocity into pressure as to cause rapid rotation.

While Professor Smith has presented some interesting features, still I do not believe they should be very much relied upon to secure economy in material by providing for a mean rather than a maximum wind pressure. It is not the pressure from a steady straight blow, so much as the aggravating effect of gusts and sudden changes. A sudden and violent gust of wind may bring about almost an explosive effect on a building. When a wave moves at high velocity and strikes a building, almost the entire velocity of the front may be converted into pressure. Before the pressure on the front can be relieved by lateral movement of the air, the wave will have passed on to the rear of the building. Owing to the high velocity, the direction of the moving particles cannot readily change, and they will take up and drag along the particles to the leeward of the building, producing a partial vacuum or negative pressure. Conditions may be such as to get the combined effects at the same instant.

R. M. Gerety, M. W. S. E.: I was thinking of the reversal of stress in the truss. When an investigation is made for that, the dead load that is assumed in the truss is usually much greater than the actual dead load and will not show a reversal of stress where the latter may actually occur. I came across a case of that kind two or three times, taking only 20 lb. wind, and since then I have been somewhat afraid of such a condition. Mr. Smetters stated that the end of the building is hard to take care of. I think that is true, and it is usually a difficult problem.

Mr. Walker: I would ask Professor Smith if he considers the total wind reaction to be taken equally by the windward and leeward columns a rational assumption; that is, if the total wind reaction is 10,000 lb.,—whether each column takes 5,000 lb. of that wind load?

Professor Smith: Yes, I consider that assumption a rational one. That is, I should regard the columns having flanges of the same design—columns of the same section—as two springs carrying the load, bending equally at the top, and therefore offering an equal resistance to that bending, and transmitting equal shear to the base. I doubt if that is perfectly true if we assume all the wind to be taken on one side of the building, but if we assume it to be divided between the two sides, it seems to me the assumption is rational.

F. P. Kellogg, M. W. S. E.: Professor Smith's expression that a column acts as two springs, I think is correct, for we assume that the truss is solid, one end moving just the same as the other. There seems to be some doubt among engineers as to the phenomenon of the suction, and its effect upon the roof. I wish to call attention to something that has been in existence for two or three hundred years in Switzerland. There, the builders do not calculate, but they put weight on the roof—rocks—for the purpose of withstanding or holding the pressure on the under side, as may be seen in pictures of mountain chalets. It looks odd to see a man build a house and then weight it down with rocks. One would suppose he would try to get it as light as possible. Instead of that, they have known for two or three hundred years there is a wind pressure and a suction inside that is more dangerous sometimes than the wind blowing outside.

Mr. Davidson: I am not quite clear as to Professor Smith's assumption in figuring the wind loads on the columns, such as he has illustrated in one of the diagrams; that is, an ordinary mill building with uniform column sections. In other words, are we to understand that the wind load is transmitted through the bottom chord of the truss, and that the two columns are to take an equal load? Personally, I have assumed that the columns on the windward side would have to take all the wind load on that side.

Professor Smith: The assumption that I am proposing is that there is a positive pressure on the windward side, and a negative pressure or pull on the leeward side, and on the inside a pressure which is the mean between those two. That one portion of the wall is then under the action of a force (assuming 20 lb. total) of 10 lb. per sq. ft., and another portion is under the action of 10 lb. per sq. ft. On the windward wall there is an inward normal component and an outward pressure, and on the leeward wall an outward pressure and an outward suction, giving an equal pressure from the wind against the wall carried by the windward column and against the wall carried by the leeward column. If this is true, then it seems to me it is quite fair to say half of the total wind reaction is carried by each column. But if, as Mr. Davidson assumes, all the pressure on the windward side must be transmitted through the truss and then go down to the foundation, it is probable there is some slight displacement of the equality of these two reactions.

Mr. Gerety: I cannot see how the size of angles used in Professor Smith's explanation is likely to be correct, because for each 3 or 4 in. angle to convey about 16 to 18 ft., they would be 5 ft. apart, and it is rather hard to know how the thing would stand up if it got the amount of wind that we usually suppost it has. About the knee braces, a man will sometimes design a mill building by bracing the bottom chords into a horizontal truss and get a part of the wind in the two gable ends of the building and then bring it down by resting it in a kind of monitor.

Mr. Davidson: One point brought out in Mr. Reichmann's written discussion is an exceedingly important one, and that is to provide sufficient web members in the column to take care of the stress which will come from the knee brace. I have seen a good many instances of lattice columns, with very light lattice members and a very heavy knee brace, and I never could figure out how the engineer who designed them could assume that his knee brace stresses would be taken up in his column,—no web member at all, simply a little light lattic work. Thoses stresses are frequently overlooked in designing work of this character.

Mr. Armstrong: The trouble is that the column is usually figured as compression only.

B. G. Williams: Referring to the case mentioned by Professor Smith, where he had a roof with chords parallel—a gable roof—I would ask whether in a case of that kind he considers the roof load as being carried from one column to the other by the webs he has?

Professor Smith: Do you refer to a saw-tooth roof?

Mr. Williams: No, just a shoulder in the level on the top, then a bottom chord, and then a truss.

Professor Smith: I should assume that the wind pressure on the windward side was just equal to that on the leeward side, and that none would have to travel through.

Mr. Williams: Not travel through the truss at all?

Professor Smith: There would not be, as under the common assumption, direct compression from the wind transmitted through the truss.

Mr. Gerety: I think that the author of this paper said something about bracing the top of the chord of the bridge so as to make the two chords act together, and found he had to put in more bracing for that purpose than what was figured for the wind. I would like to know how to figure the amount of bracing that is put in for this purpose. It seems something like the amount of lattice to be put in a lattice column. I do not know any very good rule.

Mr. Armstrong: If Mr. Reichmann were here he might answer that question better than any one present. We know it is a very difficult thing to proportion the latticing in a compression member. Some rules have been put forth, but they are all based on certain assumptions, and it would seem to me that in this case, where the entire top chord system of the bridge was regarded as one compression member, we would have to make some assumption of lateral force in order to properly design the intermediate, or lateral bracing, so that it would act as one member. At first thought, it would seem that the ordinary assumptions for wind pressure would give a lateral system heavy enough to cover the purpose of latticing for a column, regarding the top chord as a column. This might not be true near the center of the bridge, but at the ends the lateral system calculated from the wind pressure, especially on long spans, would be rather heavy.

C. A. Kyles: What would be the effect if a building were open on the windward side something like 15 ft. high, quite a large proportion of the elevation? Frequently in erecting mill buildings the side is left open down below so that the workmen can go back and forth. How would that affect the wind on the inside?

Professor Smith: I think the pressure on the inside would be the full pressure on the windward wall. The leeward wall would get the full amount of the calculated pressure on the thin plate exposed. That is, the fact that the opening was only partial would not diminish that pressure, because the air within the building would enter so freely that whatever escape there was on the leeward side would not particularly affect it. I should be inclined to design the leeward wall for the full amount of the wind pressure—the full 20 lb.

Ernest McCullough, M. W. S. E.: Suppose that the building was open partly on one side, and the leeward columns then took the entire load; how are we going to design for the leeward side, supposing a condition should arise that for some purpose or other they wanted to open the building all along on one of the sides? Then, which would be the leeward side and how should we design to take care of such condition; that is, the alteration of the building after it has been put in use?

Professor Smith: I think you would have to cultivate a trust in Providence. It is probable that we never get the amount of wind we are really now figuring, as I understand most of us are using 20 lb. wind pressure per sq. ft. The 20 lb. is due to a wind velocity of 80 miles an hour. Adopting Dine's value for *K,* that is about 0.003, one might wait for a long, long time before he ever got that wind from the most unfavorable direction of the building. There are some trusses standing in the yards of a structural steel works in this city that, according to any figures I have been able to make on them, ought to have blown out some time ago. The diagonal interior members there are made of light rods and the truss is a light truss with a light roof on it and the end of it is completely open. There ought to be enough inward pressure there to lift that like a balloon, but it has never lifted.

Professor Smith: So it is probable that when we have to remodel a building we may act on the assumption that it will stand a good deal; that is, its original factor of safety could be relied on for a good distance. It is certain that if we were designing in the first place and knew either side was likely to be opened to any extent, we would have to use the ordinary assumption that all the wind acts on one side of the building; it would not make any difference whether that were in or out on that side of the building; but it is a rare building which we would not have some means of closing up in the event of a wind of 60 to 80 miles an hour. At any rate, work would be seriously interfered with by a wind velocity of that amount, and in the other case—the infrequent case in which we are willing to have such wind force go through our buildings—probably it would be safer to take the worst effect we could get, which would be all the wind on one side.

Ernest McCullough, M. W. S. E. *(by letter):* That a suction exists on the interior of buildings when the wind blows is a fact long known to the engineering profession. It is somewhat strange, however, for a professor of structural engineering to calmly advise the skinning of sections because of the reduced wind loads by reason of this negative pressure. Mill buildings are structures in which the closest economy is attempted; they are mere shelters and, by reason of the area of ground they cover, are costly; so every reasonable attempt is made to cut the cost to the limit. The theory advanced by the author of the paper is a good one, provided the structure is always in the condition assumed at the time the design is made. If 20% of the area of the sides is given over to windows, and half the windows are open, all the advantages claimed vanish.

I had occasion at one time to design a very long and narrow building, which was later converted into a freight-storage shed. A railway track was run down the middle and along one side, on the outside. On that side all the corrugated iron was removed, thus making it a long shed open entirely on one side. If the structure had been designed in accordance with the ideas advanced in the paper under discussion, it would have failed long ago.

There is a strong suction on the leeward side of buildings, and this, acting with the wind pressure on the windward side, will more than compensate for any internal negative pressure. Good engineering design demands that a study must be made of all forces likely to endanger the stability and integrity of a structure, and the design must be made to take care of the worst probable condition. A probable condition in all buildings is that windows and doors will be open during times of heavy wind, and it is more likely that they will be open on the leeward side than on the windward side. Another probable condition is the use of the building some time with a large part of the siding removed. These two very probable conditions would demand that present methods, which are conservative, be retained for computing stresses on mill building bents.

I dissent with the recommendation of the author that wind loads be placed equally on the two walls with a view to a possible reduction of sections. I approve of his suggestion for determining accurately the point of contraflexure of columns, if there is to be any commensurate gain. I hardly understand what he means by making the amount of wind pressure for a given building a matter to be determined in the light of the exposure of the building. So far as my experience and knowledge in this matter go, I thought this was always done and is considered good practice.

With such structures as mill buildings grouped in a growing manufacturing plant, none are considered permanent and none can be designed with the idea that much shelter will be received by reason of the presence of adjoining buildings. It is true that one ton of steel may pay for many hours of engineering labor, but even now, when the worst probable condition is supposed to be assumed, we often find that the attempt to save a ton of steel is extremely costly.

One grave defect in many steel structures today is the lack of seemingly adequate wind bracing. We should not advocate anything which will appear to be an endorsement of daring design, not justified by safe precedent and good experimental work.

Albert Reichmann, M. W. S. E. (*by letter*): Mr. Smith's paper brings out some very interesting points in regard to the action of wind upon mill buildings. I am glad to note that this class of structures is receiving some consideration from engineers.

Most of the older mill buildings were poorly designed, resulting in some unfortunate accidents. Of late years the size of mill buildings has increased to a marked degree. Some of the large buildings of the Gary plant of the United States Steel Corporation are 108 ft. high and 1,400 ft. long. Structures of such size and importance deserve the most careful consideration by engineers. While the assumptions of loads and their application to structures of this class may not always have been entirely correct, I am satisfied that we have had more trouble and failures due to the lack of proper consideration of the details of these structures, than to improper assumption of their loading. I have seen plans for quite large mill buildings where the columns were composed of angles and where ample material was provided for the main sections of the columns, and also ample knee bracing was provided and properly connected to both the trusses and the columns, while the column sections were united with very small lattice bars, in some cases as small as 1¾ by 3/16 in., in place of a good size web plate. The columns of a mill building should be designed not only as a column but also as a beam, sufficiently strong to resist not only bending due to the action of the wind, but frequently the eccentric loads of traveling cranes and transverse stresses due to the movement of the traveling cranes.

The roof trusses themselves are frequently designed without properly considering the securing of the compression chords at their panel points. A great many engineers consider that, after the roof is in place and properly secured to the purlins, ample provision has been made for holding the trusses in position laterally, which in most cases is true. However, it is necessary to nave good lateral bracing for tying the panel points together to make two trusses act as a unit, as it is very essential that the structure be made absolutely safe during the course of erection. I believe this has been the cause of more mill building failures than for any other reason.

There is one feature which I think many of our engineers do not either properly understand or consider; that is, the function of lateral bracing of the compression chords of buildings or bridges. In the case of buildings, the diagonal bracing uniting the compression chords is usually considered as sway bracing, and in bridges it is usually proportioned for a wind load of 150 lb. per lineal foot, with a slight increase for longer spans. It is very important that we give this lateral bracing the most careful consideration in view of the fact that spans are now being built of great length, and the trusses are frequently placed very close together. In a truss bridge the top chords should be so united with lateral bracing that they will act laterally as a column from end to end. The top lateral bracing, therefore, acts, in a measure, to the two chords of the bridge as the lacing bars do to the individual chord members, the only difference being, as a rule, that the chords are spliced at each panel point, and are not continuous, and for that reason they require more rigid lateral bracing than in the case of a section of the chord where the material is continuous and less liable to get out of line. This lateral bracing can be figured according to the same rules which are employed in figuring lattice bars.

Recently I figured the size of laterals necessary to hold two chords of a bridge in position, and found that considerable more material was required than had been contemplated, to take care of the wind stresses. This same principle applies to two roof trusses to a certain degree, although not to as great an extent, as the weight of the steel work in most cases is all that needs to be considered in mill buildings, for after the roofing is on, the bracing is very materially relieved.

SURGING OF SYNCHRONOUS MACHINES.

Ernst J. Berg.*

Presented November 23, 1910.

Surging, or what is often called hunting of synchronous machines, resulting in pulsations of current and voltage, is one of the most perplexing and annoying of the phenomena with which the central station man meets. It is a subject which is of equal interest to the mechanical and the electrical engineer, since the causes and the remedies are as often mechanical as electrical. It is a subject which is as much alive today with the steam turbine driven generators as it was some years ago when slow-speed engine driven generators gave the engineers so much concern, when the probability was almost even that a synchronous motor or rotary converter would or would not hunt.

Surging is always associated with pulsation in speed and in power. The pulsations may be caused by the lack of uniformity of the rotative speed of the prime mover, or they may be caused by the electrical operation of the machines or by both. With the limitations of speed variation of the prime movers imposed by the electrical manufacturers, there is little likelihood that the cause of the hunting is the prime mover, if the governor-mechanism and its dashpot is of good construction. It is more likely to be due to insufficient *dampening* of the magnetic-circuit of the machines or to too much dampening, or in general to the electrical constants of the circuit. The theory of this phenomenon is fairly well understood, at least in so far as it applies to ideal machines. It seems, therefore, unnecessary to give it here except in the most general way.

For the sake of simplicity, the case of a synchronous motor operating from a large system will be considered.

Let, in Fig. 1, e_0 represent the impressed e. m. f., which will be considered of constant value and frequency; let e be the counter e. m. f. of the synchronous motor which normally at no load would be in the direction OE, but which, for some reason, is displaced α degrees behind that position. The resultant voltage e_1 causes a cross-current I_c to flow, which lags behind its e. m f., e_1, a certain angle β, which depends upon the resistance and reactance of the circuit between the bus-bars of the large generating station and the motor, and also includes the motor reactance and resistance.

By the use of complex quantities, we get:

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$$E_1 = e - e'_0 + je''_0$$

$$I_c = \frac{E_1}{Z} = \frac{e - e'_0 + je''_0}{r - jx} \text{ where } Z \text{ is the impedance above referred to.}$$

$$= \frac{(c - e'_0)\,r - e''_0\,x + j\,(\,(e - e'_0)\,x + e''_0 r)}{Z^2}$$

Thus the power consumed or received is:

$$P = \frac{e}{Z^2}\,(\,(e - e'_0)\,r - e''_0 x)$$

Since the motor is assumed to be behind the generator in time and space, it needs to be accelerated; thus, power should be received or P should be negative.

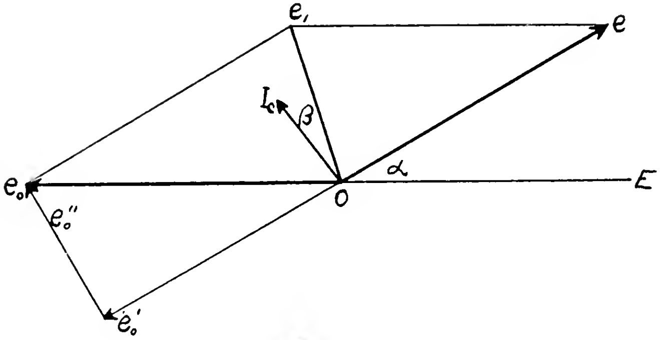

Fig. 1.

Assuming that the numerical values of e_0 and e are the same, and substituting for $e'_0 = e_0 \operatorname{Cos} \alpha = e \operatorname{Cos} \alpha$.

$$e''_0 = e_0 \operatorname{Sin} \alpha = e \operatorname{Sin} \alpha.$$

we get $$P = \frac{e^2}{Z_2}(\,(\,1 - \operatorname{Cos} \alpha\,)\,r - x \operatorname{Sin} \alpha\,)$$

but $$r = Z \operatorname{Cos}\beta, \text{ and } x = Z \operatorname{Sin}\beta.$$

thus $$P = \frac{e^2}{Z}(\,(\,1 - \operatorname{Cos} \alpha\,) \operatorname{Cos}\beta - \operatorname{Sin}\beta \operatorname{Sin} \alpha$$

$$= \frac{e^2}{Z}\;(\operatorname{Cos}\beta - \operatorname{Cos}(\,\alpha - \beta)\,),\ (A.)$$

P is negative; that is, power is received, when

Cos $(\alpha - \beta)$ is greater than Cosβ.

or $$\alpha - \beta = \beta \text{ or } \beta = \frac{\alpha}{2}$$

The power increases with increase in α up to a certain point, after which it decreases and finally becomes zero, when $\alpha = 2\beta$.

The motor is stable when, with decrease in speed—that is, with increase of α — the power received increases; it is unstable when this condition ceases. The critical value of α is readily found by differentiating the expression of P in reference to α, it is when $\alpha = \beta$.

There is a minimum value of reactance which corresponds to any value of resistance between the generators and the motor, which minimum value depends upon the amount of speed-variation or displacement of the armature by load or any other cause, it is $x = r \tan\beta = r \tan \alpha$.

What value of α can be expected?

Due to angular variation in speed, the value is perhaps as a maximum 3°; thus $\alpha = 3^\circ$ and $\beta = 3^\circ$.
therefore, $x = r \tan 3^\circ = .05r$.

Even if the resistance between the generators and the motor is as high as 10%, the required reactance for stability would be practically insignificant—far less than that which is found in any commercial machine. In other words, there can be no difficulties by such small speed-variations.

The reason for these difficulties is by far most often traced to defective design of the governing-mechanism of the prime mover or to the characteristics of the synchronous machines, which do not appear in the textbook or ideal machines.

It is well known that in order to obtain a given e. m. f. at the terminals of a generator, a certain field-excitation is required. This increases with the load, though not always with the current, which may be more or less leading or lagging; that is, magnetizing or demagnetizing.

The e. m. f. at the terminals is usually smaller than the induced e. m. f.; that is, the e. m. f. given by the rotation of the armature conductors in the resultant field. It is decreased by the impedance drop in the armature. The resultant field is caused by the m. m. f. of the field and of the armature.

The e. m. f. consumed by the armature resistance is in phase with the current. It is at all moments proportional to the current. Thus, it changes in magnitude as the current changes; that is, changes f cycles per second.

The e. m. f. consumed by the self-induction or inductive reactance of the armature is 90° ahead of the current; it also changes f cycles per second.

The flux produced by the field-excitation is constant as long as the exciting current is constant. With sudden change in excitation, it changes, however, slower than the change in excitation on account of the so-called sluggishness of the field; that is, on account of the effect of the eddy-currents, which oppose the change. Depending upon the field construction, the time required to build up the magnetism in the field may vary from a fraction of a second in laminated structures to 10 seconds or even longer in structures of solid steel, or in structures of laminated steel with imbedded squirrel-cage windings.

The flux produced by the armature m. m. f. would appear simultaneously with the current if the magnetic structure were perfectly laminated, and if the field-winding was open-circuited. In reality the structure is seldom so well laminated that no eddies occur and the field-winding is always excited; that is, closed upon itself (through the exciter); thus, at the best, the flux appears later than the current causing it, and much later if the field poles have squirrel-cage winding.

Thus, while two machines may have the same electrical constants, the same armature-resistance and reactance, the same excitation of full load and no load, the same armature reaction, their characteristics at the instant of change of load may be very different.

In the calculations of generator-characteristics, the term synchronous-reactance is usually introduced; it means a fictitious reactance which gives the same effect as that of the self-induction and armature-reaction combined. This term is justified in an ideal generator having uniform magnetic-reluctance in all positions of the armature, and having a magnetic structure which permits the flux to change at once with the change of m. m. fs. Obviously, machines with good mutual induction between field and armature-winding, a machine with squirrel-cage winding in the poles, this condition is not fulfilled.

The result of this is that if, for instance, full load is suddenly thrown on the machines of the two types, in the first type the machine will take its load when the speed has dropped so that the angle between induced e. m. f. and terminal e. m. f. is say 15°, whereas, in the latter type it may be only 1°. To be sure, after a short time—a few seconds—the two machines will have the same phase displacement between the induced and terminal e. m. f.

The same applies to the synchronous motor, but in this case the different characteristics play an important part in the stability of operation.

As stated above, for sudden variations in load the reactions in machines of greatly damped field-circuits are largely governed by the ohmic resistance and the true inductance between the generators and the motor; whereas, with ideal machines the reactions are governed by the synchronous reactance which usually is many times as great as the true reactance.

It is of interest to study the behavior of the two types of motors when operated from a large generating station over a non-inductive line such as a cable with a certain ohmic resistance in the line.

Let, in each case, the total resistance in the circuit be 10%, and assume the true reactance of the armature to be 2%

and the synchronous reactance 67%. Assume further that the numerical values of the impressed and counter e. m. f. are the same. Referring to equation *A* we have.

For the ideal motor,

$e = e_0 = 1$
$r = .10$
$x = .67.$

For the damped motor—for a sudden load,

$e = e_0 = 1$
$r = .10$
$x = .02.$

Thus, in the first case, $\tan\beta = \frac{.67}{.10} = 6.7$

$\beta = 81° \, 30'.$

In the second case, $\tan\beta = \frac{.02}{.10} = .2$ and $\beta = 11° \, 20'.$

The curves on Fig. 2 have been calculated by assuming different values of α and solving for P and the current. It is seen that the ideal motor, if loaded to full load, drops behind a certain angle about 44°, so that there is ample margin in output. This increase in the angle α gives an increase in ability to carry load, or in general the motor has all desirable characteristics.

The second type of motor—the motor with excessively damped field-circuit—behaves, however, entirely different. This motor, while it can be loaded up to the same output as the first type, if the load increases slowly so that the armature reaction has time to exert its influence will break down immediately if suddenly more than about 20% of full load is thrown on, as seen from Fig. 2. Thus, we conclude that such motor should have some external reactance if it shall be able to carry pulsating load. It is readily seen that while both types of motors are by theory less stable the greater the resistance, the second type is far more sensitive.

A motor of the first type,—that is, a motor of laminated field, frequently used some years ago—while often operating satisfactorily, may, of course, be unstable, on account of excessive reactance.

Assume, for instance, that such a motor is operated over a line of 10% resistance and 20% reactance. The total reactance would then be 87% and the characteristics would be those shown in *C* and *C′*, Fig. 2. As seen, the motor is not able to carry full load and it is extremely sensitive from half load up.

Thus, too much reactance is as detrimental as too low reactance. A motor of this latter type would undoubtedly benefit by a squirrel-cage winding on the field, since such winding reduces the armature self-induction to some extent. Such motor would run much more stably if by some arrangement of the supply circuit its reactance could be decreased.

This explains why, with the old type of motors, it was always an advantage to reduce the self-induction in the lines connecting the motor with the generators, whereas, with modern

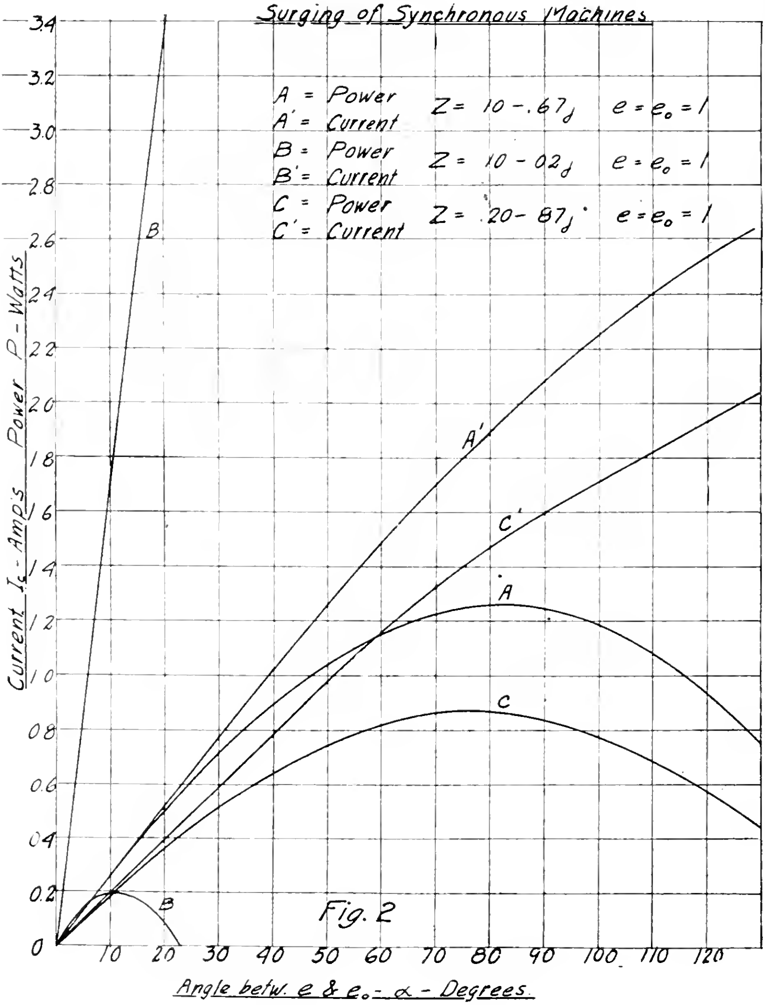

Fig. 2

high-speed motors and especially in the case of parallel operation of turbo-generators, it is often an advantage and at times a necessity to install extra reactances in order to obtain stability.

Every synchronous machine has a natural period, that is, a period at which it will oscillate when adjusting itself from one load to another. The periodicity is practically proportional to the square root of the field-excitation and inversely proportional to the square root of the moment of inertia.

While such oscillations always take place with changes of load, they are usually of little importance since they cover a small phase angle only. If, however, the synchronous motor is supplied power from an alternator whose speed for some reason or other pulsates at the same rate as the natural period of the motor, then a condition of resonance takes place and the machines cannot operate satisfactorily in parallel. In such case, the remedy is obviously to change the natural period, which can be done by increasing or decreasing the moment of inertia, or by changing the air-gap and thereby the excitation.

In general, it can be concluded as far as the electrical side of the surging problem is concerned, it can be solved by either one or more of the following alternatives:

1. Reduce the ohmic resistance between the machines.
2. Exclude all external reactances and put field-damping devices on machines of laminated fields and quick magnetic circuit, especially if the synchronous impedance is great; that is, if they, as generators, have poor regulation.
3. Add extra reactance in high-speed machines having good mutual induction between field and armature and sluggish magnetic circuit.
4. Change the natural period by change of air-gap or addition of fly wheel, etc.

While thus something can be done by changing the electrical constants, it is but seldom that this is necessary. Ninety-five cases of every hundred can be traced back to some mechanical defect of the prime mover. Usually the governor is too sensitive, or there is some play in the various links connecting the governor proper with the steam-admitting valves. Sometimes, by the very nature of the drive, difficulties can be anticipated; for instance, when several generators or motors are belted to the same countershafting, when it is always possible that the pulleys might be of slightly different diameters or the belts of greatly different quality.

In the case of hunting between direct-connected engine-driven units, it is easily ascertained if the governing-mechanism is at fault by disconnecting it and operating by throttling. Should hunting still persist, it would seem necessary to resort to some of the three electrical remedies suggested, and if these are impractical, to add some fly-wheel capacity.

In conclusion, it is believed that any surging difficulty can be solved by the remedies suggested; indeed, with practical experience of a large number of cases, the writer has never met a case which could not be disposed of by them.

February, 1911

DISCUSSION.

Peter Junkersfeld, M. W. S. E.: The subject of surging of synchronous machines has received so much study for a great many years, and with the addition of Dr. Berg's very able paper this evening, one would be bold indeed to attempt to add anything further. I might perhaps call attention to a few examples that have occurred in this part of the country in which some of Dr. Berg's remedies have cured the trouble.

My first recollection of hunting of synchronous machines here in Chicago was at a time when alternating current distribution was a very, very small part of the total. The particular circuit arrangement happened to be such that the load on the largest circuit was too heavy for the largest machines. The machines were 120 kw., single-phase alternators, driven from a line shaft. So the thing to do was to locate two of them side by side and run them in parallel from the same line shaft. Some trouble ensued, as might be expected. Those machines, however, were run in parallel for several weeks until the circuit conditions could be remedied. That was largely a case of the prime mover, the transmission of the power through the belts to the pulleys, and it was a matter of keeping the belts in exactly the same condition, so that the machines could divide the load and not hunt.

The next experience here in Chicago that I remember was when the first rotary converters were installed. Those, however, gave us very little trouble. They were 100 kw. machines, taking current over a transmission line from an inverted 250 kw. rotary. The power and speed of the inverted rotary were quite constant and there was no trouble to speak of for nearly a year, until an attempt was made then to run engine driven, double current machines in parallel with this inverted rotary, and that, by the way, I believe was some of the first work Dr. Berg did in Chicago; at least, it was the first time I had the pleasure of meeting him here. There was considerable trouble, but only for a short time. It was a matter of getting the electrical conditions straightened out and getting the engine in good shape so that it would regulate. That was a case of 25 cycle units. It was some twelve and a half or thirteen years ago. Ten or eleven years ago the first 60 cycle direct coupled engine driven machines were put into service in the Fifty-sixth street station of the now Commonwealth Edison Company, one 600 horse power, and two 1,200 horse power units. In that case the trouble was quite considerable for a long while. It was a matter of having the dashpot too sluggish or too sensitive, but after a considerable amount of work that was cured.

Some trouble occurred here in Chicago running motor generators from the 25 cycle system. When the first motor generators were run in Chicago, there were comparatively few of them and the source of power was principally from a large double current generator, which, however, carried some elevated railway load, and this meant a great deal of fluctuation of load and consequently of speed of that engine. The hunting troubles in that case were minimized, although not entirely remedied, by anti-hunting devices on the pole pieces. A year or two later, by squirrel cage windings on the motor the troubles were further reduced.

Those troubles, however, have all disappeared since the advent of the steam turbine and the very much larger units where the load fluctuations do not affect the speed of the prime mover. I do not know of any recent troubles of any consequence, although there are some in connection with coupling up smaller outside plants; but the remedies that you have heard in most cases are effective as soon as we know all the conditions and know how to intelligently apply the remedy.

E. E. Dudley: The question came up with reference to the statement which Dr. Berg made regarding the effect of undue sensitiveness in the governor. It may be that I have mistaken Dr. Berg's intention in this matter, but it raised a question in my mind this afternoon whether it might be due not so much to undue sensitiveness as unregulated sensitiveness. It seems to me that in most cases we can get much better regulation with a sensitive governor if we can regulate the sensitiveness in such a way as to prevent the governor over-traveling, because if the governor has great inertia it is undoubtedly possible for it to have a pendulum effect, that is, it will swing forward of the neutral point in some cases without a dashpot as far or farther than it retreated with the decreased speed. If it is possible to make a governor sensitive enough so that with a slight decrease in speed it will make a large immediate alteration in the position of the trip or mechanism for regulating the speed, but having made that alteration will not go so far as to cause the engine to greatly over-travel and the governor not come back to the neutral point, under those conditions it seems to me that a sensitive governor would be much more effective in holding the speed somewhere near constant and thereby at least cut out a portion of the tendency to hunt. Of course, that does not cut out the pendulum effect of the rotating part of the synchronous converter or synchronous apparatus, but it seems that, with the experience that the Lombard Governor Company has had in connection with water-wheel governors and, to a certain extent, with gas-engine governors, we would get much better effect with a very sensitive governor, so controlled as to prevent a great over-travel, than we do with a sluggish governor, which has a decided pendulum effect due to the great inertia of the rotating parts and to their great weight, and, in addition, the vertical weight on the connecting parts. While this might not be of any great importance with a small high-speed engine in which the trip mechanism did not perform any great amount of work, it becomes of considerable importance on a large engine where the trip mechanism performs a great deal of work, where there may be considerable lag, especially in gas engines and in water wheel work. It has been very evident that if we can make the governor in a way synchronous and prevent it from setting up synchronous variations in speed on its own account, and at the same time use a governor mechanism of extreme sensitiveness, so that instead of allowing the speed to drop to 3% or sometimes 4 or 5% before it takes action, it will begin to take action on probably a quarter of 1% drop in speed, and the action would become effective almost instantly. Of course that is comparative. It is not instantaneous, by any means, but it is so near it that it does not seem to me to give synchronous machinery as much of an opportunity to lag behind. It would not set up objectionable oscillations in the engine or water-wheel driven unit.

The point on which I thoroughly agree with the author is that of lost motion in the governor connections. I think people who have not had a great deal of experience with water-wheel and engine-driven machines cannot realize how very small an amount of lost motion can be felt. That lost motion, if it is taken close to the governor itself, is multiplied several times by lever connections. The amount is very minute, in some cases a matter of only one or two thousandths of an inch, and if it is possible to eliminate even that small amount by the use of hardened steel bushings in accurately reamed holes, it seems to me that the expense of that construction is paid back largely in dividends by the increase in the fineness in the smoothness of the regulation. The smoothness of the speed-change curve it seems to me has a great deal of effect on the whole system all the way through, not only inside the plant itself in cross currents, but outside in the synchronous machinery. It is certainly evident that we cannot get a smooth speed-change curve unless every portion of the apparatus all through the governor to the valve or gate mechanism, as the case may be, is of an accuracy that might be considered almost too great a refinement; I do not know that it can be too great. So many cases come up where the difference between the two sides of a cross-compound engine, due to torsion on the cross-connecting shaft between the governor on one side and the valve mechanism on the other,—a torsion that seems to be too small to have any appreciable effect, taken in connection with a very slight amount of lost motion at one of those joints,—will wreck the regulation entirely.

D. W. Roper, M. W. S. E.: The earliest experience I had in operating alternators in parallel was at the factory in Schenectady, under Dr. Berg's direction.

Some experiments were made on running several different types of machines in parallel. We wired up a little switchboard there, especially for the purpose, and had all sorts of precautions, such as fuses and other devices, synchronizing connections, and so forth. After a little experimenting there, we found that through the kindness of Dr. Berg we had been supplied with machines which ran very easily in parallel and we could close the switches at random on the board field switches, either the first or the last as we pleased, and they ran right along in parallel as though they had been built to do so. There were four different types of machines, as I recall it. One was a single-phase machine, and another was a three-phase machine, of which we were using one phase. The third was a monocyclic machine. The fourth was a single-phase machine,—one with the old pancake armature coils. The safety devices were not of much use to us, because these machines were all of a capacity of 30 or 60 kw. or thereabouts,—perhaps one of them was 100 kw. We could throw one with full excitation on to another one with an open field and it would not take a full load current, which made the operation very simple.

After a few weeks experimenting I thought I knew all about running alternators in parallel, but after taking up work with a central station, where they had their troubles, I found I was mistaken. The station was one with single-phase distribution entirely, and the practice had been to run the alternators singly,—that is, in the old fasihoned style, with a switchboard arrangement so that they could switch the circuits from one alternator to another. As they put on an alternator they would connect it to a bus and then throw the circuits over to that bus one at a time, which, of course, meant interrupting some of the circuits every time an additional machine was put on. So they desired to devise a scheme, if possible, to operate those machines in parallel. There were two stations. One of them had Corliss engines with monocyclic machines in which the monocyclic winding was not used. In trying to operate those machines in parallel we tried them first when they were not carrying any load, and found that the alternators exhibited no tendency whatever to remain in parallel when once properly connected. The two alternators would gradually drift slowly out of phase as the two engines would differ slightly in speed and the armature current would increase, gradually but continuously, up to full load and beyond. Then we would have to pull the fields and stop the process. In that case the monocyclic winding had not been brought to the switchboard, but there were switches available on the board,—old fashioned knife switches on the front of the board,—and we tried the scheme of bringing the monocyclic winding, the teaser winding, so-called, to the switchboard and connecting it up to a piece of short bus. We found by using the monocyclic winding that the same two machines which exhibted no tendency whatever when operating single-phase, remained together very nicely indeed. In fact, we were unable by any process to throw them out of step when the teaser winding was connected up as well as the main winding, and those machines operated in regular practice, without any material difficulty that I recall.

This experiment turning out so successfully, it was suggested that we try the other station where there were vertical three-cylinder compound engines connected to alternators whose armature had a continuous winding tapped off at four points to give a two-phase connection. They were designed for two-phase machines, but were being operated single-phase. These machines would exhibit a very slight tendency to stay in step, there being a slight hunting, starting sometimes a few seconds and sometimes a minute or so after they were connected. Once started, though, the hunting would increase rapidly. Having heard of dashpots and such devices on governors, we decided to investigate this pair of engines which were duplicates, and in order to try that idea we adopted the very simple scheme of running one engine on the by-pass using only the two low-pressure cylinders, which cut out the governor in one of them entirely. Of course, that is rather dangerous practice, because if you should lose your load you would have a case of racing on hand immediately; but we took care of that by keeping a man alongside of the by-pass, and found that those two machines operated in that manner ran very nicely indeed. They would stay in step and we could put load on them which would be carried very nicely, but, of course, it was not a scheme that could be used in regular practice,—entirely too dangerous.

We then investigated the governor for lost motion, as has been suggested this evening, and found by putting a bar under the valve rod while the engine was standing still and prying up on it we could move the valve something like ¾ in. So we had lost motion all right. We fixed that up a little, took most of it out, and then put heavy oil in the dashpot. It was not quite heavy enough the first time, so we remedied that by making a much smaller hole in the by-pass around the two ends of the dashpot, making it a needle hole instead of a ¼ in. hole as it was before. After those changes had been made, it was possible to run the machines in parallel if some expert was on hand to adjust the machines and shift the load and do other things that were necessary in order to keep them operating, but we never were able to get them in good enough condition to operate in practice without having somebody on hand to assist the engineer.

Another case that occurred nearer home Mr. Junkersfeld did not mention,—perhaps he has forgotten it,—was operating a 1000 kw. rotary from engine driven units. In that case we also got some fluctuations of voltage on the direct current side. That was about the time that the Fisk Street station was started, and the rotary was operated from our engine-driven units at Harrison Street and caused some very serious fluctuations for a while. We started to help that by putting dampening devices on the pole pieces, as has been mentioned as one of the cures, but before we had the work completed we decided to run Harrison Street and Fisk Street in parallel, so that the current really came from Fisk Street and then all the oscillation stopped. In other words, the rotary which gave fluctuation on an engine ran very smoothly on a turbine, which is also another way of curing hunting.

William B. Jackson, M. W. S. E.: I have been wondering whether there are any cases that have not been cured in some way or another. I would be glad to have Dr. Berg's opinion regarding this matter, based upon his experience.

In the early days of parallel operation we had considerable difficulty in paralleling some of the inductor type engine generators, and I remember in one case the trouble was cured by having the several generators excited from a single engine driven exciter, instead of from their own individual exciters as had been the case theretofore. In another case of serious difficulty, dampening bars were placed upon the inductors as a last resort and proved thoroughly effective. Many expedients were tried before dampening bars were resorted to, such as blocking the engine governors of the operating machines, but without satisfactory results. When the machines were operated at half speed they paralleled satisfactorily, and when the low pressure connecting rod of one engine was disconnected, and it was operated with the high pressure cylinder alone, its generator operated perfectly with the others, but, as in Mr. Roper's case, these were not satisfactory conditions for regular operation.

In another case, two engine generators of the revolving armature type positively refused to operate in parallel. No amount of adjusting of the engine governors or of the engines themselves would bring the machines to satisfactory parallel operation, and in this case the armatures were torn down and completely rebuilt with increased air gap and changed electrical constants.

It would seem that troublesome belt driven machines have always been made to parallel if there was sufficient incentive to warrant the trouble. I happen to remember one case where the belt pulleys would not give quite the correct speed to permit of parallel operation, and we pasted layer after layer of paper on one of the generator pulleys until the proper diameter was reached when the machines operated beautifully together.

I do not remember of having come in contact with a case of surging of alternators where some sort of device has not been worked out to make parallel operation possible, and am interested to know if there are any cases that have not been cured in some manner.

This paper has been an extremely interesting and instructive one, and we may all join the Chairman in thinking of how easy it is to parallel sychronous apparatus in the light of knowledge of today as compared with the situation fifteen years or even ten years ago, when in paralleling many engine-generator sets we were greatly worried for fear the machines would never be brought to satisfactory parallel operation, though it may be added that they seem to have eventually been brought together by some method or other.

Frank F. Heck, M. W. S. E.: I would like to ask Mr. Dudley a question in connection with using a very sensitive governor. Suppose you have a sudden fluctuation in load immediately after cut-off takes place and are using a very sensitive governor. Are you not going to get into trouble?

Mr. Dudley: It seems to me that might be the case in a good many conditions. It undoubtedly is in gas-engine practice where conditions are undoubtedly worse than in steam-engine practice, owing to the high initial pressure at the beginning stroke. Under those conditions there must necessarily be some compensating effects which will in a sense cause the governor to do a little thinking on its own account. Those devices have been applied on gas-engine and water-wheel work, but not as frequently on steam-engine work. With the ordinary type of Corliss governor I should say that if it was made sensitive enough and with the usual type of dashpot, there would be great probability that the speed variation would be on the wrong side of normal immediately after the next stroke. But I suppose I should withdraw my statement as a general one in connection with all types of steam-engine governors. It would undoubtedly be necessary to add a compensation other than the compensation of the plain dashpot. The plain dashpot merely prevents the governor from acting as rapidly as it might under a certain definite and sometimes large impulse, and really is more a brake than anything else. The compensation in the dashpot as a rule is not carried beyond that point. If the dashpot could be equipped with some method of automatically regulating the amount of oil which would pass the piston in proportion to the tendency to speed change, it seems to me this would in a large measure solve the difficulty that has been brought out.

G. W. Cravens: When I received an "advance" copy of this paper, through the kindness of the Secretary, I immediately recalled having heard Dr. Berg give a talk on this same subject in Schenectady some five or six years ago, at which time he had a great deal to say about cross current in the neutral. I notice that tonight he has practically ignored that, mentioning it only once. I do not know whether this was intentional or not. I remember one statement he made at that time was that in dealing with cross currents in the neutral we had practically a single phase triple frequency machine of three circuits. Perhaps he would like to say something tonight in regard to the question of cross currents in the neutral.

G. W. Brady, JUN. W. S. E.: We have at the present time a need for some single-phase motors that will run in synchronism. I would like to ask if there is anything of that nature on the market that can be depended on, or if it is possible to build them.

E. J. Carroll: I would like to ask if the operation of 60 cycle generators driven by a gas engine is a practical thing, operating in parallel.

H. S. Pardee: I would like to ask about the matter of synchronous impedance. A very interesting feature that is brought out in the paper is the emphasis that the ordinary idea of synchronous impedance is not at all applicable to this work. A great many formulæ are derived on the assumption of the ideal machine in which the impedance is the lumped effect of armature reaction and natural reaction, and that assumption is perfectly correct in figuring the reaction of a machine in which the changes take place in a slow time, that is, the error is negligible; but when we come to sudden changes in the load, especially periodic changes, such as hunting, Dr. Berg has shown that the synchronous impedance is very much in error. For instance, the angle between the interchange current and the interchange speed he has figured in one case to be 81° in the ideal case, and only 11° in the case of the dampened motor. He says that the machine acts practically as if there was no armature reaction. Now if the matter of armature reaction was to be calculated,—that is, if in synchronous impedance we were to include that varying,—it seems to me the calculation would be hopelessly complicated, but he has thrown it out altogether.

Under what conditions is it practical to assume the synchronous impedance is simply the actual impedance, or when must one take into account the armature reaction? There is a very large difference.

W. E. Symons, M. W. S. E.: I concur in the remarks of the previous speakers who said there was not much in this paper to discuss or criticise, as the author has so ably covered all the points in question that it does not leave much talking ground. That is largely confined to what we might call an experience meeting, but it is from the practical experience we have in working out all of these problems that we learn some of our best lessons.

In my own experience, which has been largely that of an operating engineer or of a supervisory character, I have not made a special study of electrical engineering, and therefore do not claim to be able to criticise such problems as have been treated by those who have made a life study of them and who are well qualified to handle them. In my work of a supervisory character, however, troubles similar to those mentioned here this evening have not infrequently arisen, and when we have called on an electrical engineer to help us to remedy our trouble, we have sometimes found ourselves in the dark, and although we usually succeeded in partially or wholly remedying the difficulty, I am confident if we had been in possession of the information contained in this paper, and the discussion imparted by the members this evening, we would have been able to have disposed of all troubles of this character.

This paper and the discussion which has followed is, therefore a valuable addition to the proceedings of this Society, and I think the information might well be used in the future as a text-book or treatise on diseases of electrical machines of this character and the remedies therefor.

In the matter of steam engines, there are frequently troubles.

apparently of a serious character, which could and should be either avoided or remedied by very simple means. In saying this I recognize that it is in the nature of a criticism of some high grade steam engine builders. I have had considerable experience in the purchase, installation, and operation of many steam-engine plants and have been in close touch with the people who design, build, install, and operate them, but have never yet observed in their catalogues, or heard from their representatives, any particular stress laid upon that vital point of steam engine operation and success,—the governor, its care and treatment. The builders' catalogues do, of course, through the medium of the photographer's art, elaborate on all parts of their product, including the governor, but I have not seen information in their catalogues, or learned of any special instruction being given by their erecting engineers, as to the exact dimensions, quality, conditions, and treatment of the governor belt. This matter is usaully treated as one of the little, insignificant trimmings of the steam engine, when in reality it is a most vital part, in so far as it affects the engine's behavior.

I have known of one or two cases of high-duty steam engines, controlled by the Porter type of governor, that behaved badly at times by racing, the inequalities of speed being such as to seriously interfere with the operation of the plant. One of these engines was driving an electric plant and developed trouble which the engineer in charge failed to locate; this necessitated calling expert mechanics from the works where the engine was built, several hundred miles distant, to locate and remedy the trouble. On investigation it was found that there was absolutely nothing the matter with the engine. The trouble was due to extreme changes of temperature in the engine room caused by opening the windows in zero weather and permitting a draft that chilled, and in some cases had practically solidified, the oil in the governor's dashpot or reservoir, thus destroying the sensitive features so essential in an engine governor. This of course caused the engine to *race badly*. So, after much loss in time and money, it was found the trouble was one of *engine room ventilation* and not a scientific or engineering question.

This was seemingly a small matter, but not unlike another case in which a high-duty engine was driving a large industrial works, were uniformity of speed was most essential. The load carried fluctuated considerably, however, and the engine became less efficient in meeting these conditions. As in the previous case mentioned, several expert engineers were called in who in turn took indicator cards and worked up performance sheets accompanied by a theoretic analysis of the valve gears, valve adjustment, steam distribution, and their effect on, or relation to, engine racing, etc., but to no avail. Finally the builders of the engine were appealed to, and in response they sent two skilled experts several hundred miles, ostensibly to remedy a difficulty involving engineering knowledge of a high character, but after observing the behavior of this engine a few minutes, the experts cut about two inches from the governor belt, properly laced it together, and returned home.

Quite a number of cases similar to those mentioned have come under my notice, with the result that each has taught a lesson that has proven most valuable in many instances, and to my mind emphasizes the necessity of giving more attention to the design, construction, and care of engine governors than they have formerly received.

Mr. Hirt: Under what conditions would a synchronous motor refuse to start, having started previously and showing no abnormal conditions which would cause it to refuse to start? It is a question which has troubled me. I would like very much to have Dr. Berg answer that question.

CLOSURE.

Dr. Berg: I cannot discuss the questions in the order in which they were asked, as I did not write them down at the time.

In regard to the 60 cycle gas engine driven generator, there is no reason that I can see why 60 cycle operation should not be satisfactory, theoretically speaking. We can get the proper speed regulation by a suitable fly wheel. The difficulty, if there is any, is that a gas engine once in a while misses fire, and of course under such a condition we get rather unsteady speed. I am quite convinced, however, that with proper squirrel cage windings on the field structure, parallel operation can be made satisfactory and I should not hesitate to install some units of fair size—say two or three hundred kilowatts. I know of direct-connected 60 cycle machines that are operating satisfactorily.

Regarding triple frequency currents. It is quite possible, as I stated, to write a fair sized volume on this subject of hunting. The reason that I left out a great many phases was that they were relatively well known. The particular point that was brought up here, and which I believe is new,—at least it is new to me.—is the explanation of why some of these machines of high speed require external reactance. Triple frequency currents and their effects in the neutral is a large subject in itself. It is safe to say that they do not play anything more than a theoretical role—hardly a role of any consequence—in connection with hunting.

Regarding sensitive governors, all experience has shown that the very sensitive governor is not a good governor as far as parallel operation is concerned. In fact, if it were practical to operate machines on the throttle,—if we could keep a man there all the time to shut off steam when the load goes off, etc.,—we would probably have little or no trouble in parallel operation. I quite agree with Mr. Dudley in regard to the inertia of the governor; if there is a great deal of inertia and the governor itself begins to hunt, the difficulties are increased. But I think there is not much trouble on that score. The fact seems to be that we should have a powerful dashpot, so that the governor is almost inoperative except in emergency. The best dashpot arrangement that I know of practically locks the governor, so that the speed will drop considerably with increasing load, and it is only when the speed varies much that the by-pass is open and the governor can begin to act. We can readily see why the sensitive governor can give trouble in hunting. At such time power is being transferred from one machine to the other due to electrical action; when power is transferred from one to the other the speed will pulsate, which causes a pulsation in steam admission. At such times we do not want a governor that opens up when the alternators want to have steam; we want one that does not give it to them.

Regarding the remedies, the fact of the matter is, it is now relatively easy to curé hunting, but this was not the case eighteen years ago.

Parallel operation of single-phase alternators is practical. They run in parallel quite as well as three-phase machines. Of course they give less output for a given size, but I should not hesitate to install and run single-phase synchronous motors with any single-phase machines; there are a few things to be considered,—the heating of the pole pieces, etc.,—but these are easy problems. Single-phase motors are not self-starting; multi-phase synchronous motors usually are; they will start on two principles, either as induction motors or as hysteresis motors. In the case of the induction motor, the field poles and windings of the machines act as secondaries with the armatures as primary. It is well known that an induction motor, to give high starting torque, should have high armature resistance. Therefore, a synchronous motor with low resistance pole windings is likely to start less readily than one with high resistance. The hysteresis motor starts because of the fact that the magnetism does not follow the change in current; it takes a certain time for it to appear or disappear; the magnetization lags behind the current at a certain angle,—the angle of hysteresis advance.

But why the particular motor which used to start does not start now is difficult to explain offhand. It is possible, perhaps, that the air gaps are unequal because the bearings in the machine have been worn. That has a great effect on the synchronous motor in starting. If that is not the reason, it is possible that in the operation of starting some turns are being short-circuited in the field winding turns on perhaps two spools, or perhaps one spool, and that forms a secondary which carries an enormous current, causing unbalanced torque. One may not readily know of this short-circuit, since it is possible that when the machine is running and there is only a moderate voltage on the field, it will not exist.

While there are many possible explanations, I think that one or the other is the case, and presumably it is the bearing question; but if it is not the bearing, it may be the field.

Natural frequency. The beats of these machines usually range from 60 to 90 per minute. I have never found them higher than a little over 100, 105, or so, and have never seen them lower than 60. It may take ten seconds for the field to build up in such a machine, so that when the load changes as frequently as it does during hunting, I should think that one could very well disregard the armature reaction and consider only the self-induction. The two curves that are given in the paper thus represent the two extremes. Depending upon the period of the swing, we use either at these curves, or their average.

The mathematics involved in including the time lag is too complex for a paper of this kind.

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS.

Extra Meeting January 18, 1911.

An extra meeting of the Society (No. 728) and of the Bridge and Structural Section was held Wednesday evening, January 18, 1911. The meeting was called to order at 8:15 p. m. by the Chairman, T. L. Condron, with about 35 members and guests in attendance.

This was the Annual Meeting of the Section and for the election of the Executive Committee of the Section for 1911. The result of the balloting was the election of Mr. John Brunner for Chairman, Mr. F. E. Davidson for Vice-Chairman, and Mr. I. F. Stern for member of the Committee. Mr. T. L. Condron and Mr. W. C. Armstrong remain on the Committee as holdovers.

This business being concluded a general discussion followed on working in concrete and its protection in freezing weather presented by Messrs. Condron, Allen, Finley, Davidson and McCullough. The meeting adjourned about 10:15 p. m.

Extra Meeting January 25, 1911.

An extra meeting of the Society (No. 729), the Annual Meeting of the Electrical Section in joint session with the Chicago Section A. I. E. E., was held Wednesday evening, January 25, 1911.

In the absence of the Chairman, Mr. G. H. Lukes, President O. P. Chamberlain called the meeting to order at 8:25 p. m. with about 100 in attendance, including many ladies. The first business of the meeting was the election of the Executive Committee of the Electrical Section, W. S. E., for 1911, nominated at the preceding meeting. These were:

G. T. Seely, for Chairman;
J. R. Cravath, for Vice-Chairman;
G. H. Lukes, member of committee for three years,
with Messrs. Abbott and Woodworth as holdovers.

On motion, duly seconded, the Secretary was instructed to cast the vote of the Section in favor of the nominees, which was done.

President Chamberlain then introduced Mr. Seely, the newly elected Chairman, who made a brief address and then introduced Prof. Morgan Brooks, M. W. S. E. of the State University at Urbana. Professor Brooks gave a pleasant, interesting and instructive talk about his recent trip around the globe under the title "Inductions from a Closed Circuit of the Globe," which was illustrated by a number of stereopticon views of the trip.

The meeting adjourned about 10 p. m., all expressing themselves as greatly pleased with the address and illustrations.

Extra Meeting January 30, 1911.

An extra meeting of the Society (No. 730), being the Annual Meeting of the Hydraulic, Sanitary and Municipal Section, was held Monday evening, January 30, 1911. The meeting was called to order by the Chairman, John Ericson, at 8:15 p. m., with about 45 members and guests in attendance.

The election of members of the Executive Committee for 1911 was in order and the following were nominated and elected:

L. K. Sherman, Chairman;
C. B. Burdick, Vice-Chairman;
G. L. Clausen and C. D. Hill, members of the Committee.
The retiring Chairman, Mr. John Ericson, remains on the Committee.

Following this business, Mr. C. D. Hill, M. W. S. E., was introduced who gave an instructive and illustrated talk on the Sewers in Chicago. Mr. Langdon Pearse, M. W. S. E., followed with an illustrated address on the Sewage Dispoal Problem in this country and in Europe.

Discussion followed from Messrs. Shields, Ashley, Potter, Pearse, Alvord and Hill.

The meeting adjourned at 10:35 p. m.

Regular Meeting February 1, 1911.

A regular meeting of the Society (No. 731) was held Wednesday evening, February 1, 1911. President O. P. Chamberlain called the meeting to order at 8:30 p. m. with about 50 members and guests in attendance. The reading of the minutes of the previous meetings was dispensed with. The Secretary reported from the Board of Direction the list of names of applicants for membership:

Adolph F. L. Heinicke, St. Louis, Mo.
Cesare Barbieri, Chicago.
Welland F. Sargent, Oak Park Ill.
Oscar F. Gayton, Chicago.
Harry H. Stoek, Urbana, Ill.
Curtis C. Saner, Chicago, transfer.

Also reported from the Board of Direction that the following had been elected into membership:

Edward N. Roth, Chicago	Associate Member
Harry W. Myers, Chicago	Associate Member
W. F. Jordan, Chicago	Associate Member
Herbert H. Evans, Chicago	Member
George E. Cadman, Chicago	Junior Member
H. B. Kirkland, Chicago	Associate Member
W. J. Miskella, Chicago, transfer	Associate Member
Donald C. Barrett, Chicago	Associate Member
Justus B. Eddy, Chicago	Associate Member
B. E. Strohm, Chicago	Associate Member
H. J. Fixmer, Chicago transfer	Associate Member
Edward J. Sterba, Chicago	Associate Member
V. L. Page, Chicago	Associate Member
Walter D. Guy, Chicago, transfer	Associate Member

Also reported that a letter had been received from Mr. Alfred Noble, M. W. S. E., relative to proposed legislation for an increase of the Engineer Corps of the Army, an amendment to which bill had been considered. The following report was presented:

Chicago, January 31, 1911.

Board of Direction,
Western Society of Engineers,
Monadnock Block, Chicago.

Dear Sirs:

The Committee appointed yesterday to report on the advisability of endorsing the amendment to H. R. Bill No. 7117, referred to in Mr. Noble's letter of December 22d, 1910, hereto attached, respectfully recommend that no action be taken by the Society.

Respectfully submitted,
(Signed) A. Bement,
Hiero B. Herr,
O. F. Strehlow,
Chairman.

This report, on motion duly seconded, was accepted.

The following resolution was presented by Mr. A. Bement, duly seconded, and voted on affirmatively:

Whereas, the Western Society of Engineers has been especially instrumental in bringing about the establishment of a Geological

Survey for the State of Illinois, also the establishment of a College of Mines at the University of Illinois, and

Whereas, the Society, having been interested in these organizations, and in view of their importance to the general public, be it

Resolved, that a committee, composed of not less than three members of the Society, be appointed to inquire into the status of the work performed by these organizations and that such committee report the results of its examination to the Society with such recommendations as may seem to it to be desirable.

January 18, 1911. (Signed) A. BEMENT.

The President appointed on this Committee Mr. A. Bement, Chairman, W. W. Curtis and L. C. Fritch.

The President then introduced Mr. A. Bement, who after a few introductory and explanatory remarks read the paper, The Public and the Public Utility Corporation. Discussion followed from Mr. C. V. Weston (by letter), Mr. Larned, on behalf of the Telephone Company; Mr. J. G. Wray, of the same company; Messrs. P. Junkersfeld, D. W. Roper and R. F. Schuchardt, of the Commonwealth Edison Company, and Messrs. John Ericson, C. D. Hill, J. W. Mabbs, J. A. Hammond, G. L. Clausen, J. R. Cravath, and a closure from Mr. Bement.

Meeting adjourned about 10:50 p. m.

Extra Meeting February 8, 1911.

An extra meeting of the Society (No. 732) was held Wednesday evening, February 8, 1911. The meeting was called to order at 8:20 p. m. by President Chamberlain with about 70 members and guests in attendance.

The paper by A. S. Robinson, M. W. S. E., "The Shuttle System for Chicago Subways," was read by the Secretary in the absence of the author. The Secretary also read a letter from Bion J. Arnold expressing his interest in the paper and regret he would not be present. A written discussion from Mr. John Ericson was also read. General discussion followed from Messrs. George Weston, A. J. Saxe, W. G. Boucher, H. H. Evans, E. D. Martin, P. E. Green, H. J. Fixmer, W. D. Gerber, and President Chamberlain. Adjourned about 9:40 p. m.

Extra Meeting February 15, 1911.

An extra meeting of the Society (No. 733) was held Wednesday evening, February 15, 1911.

The meeting was called to order at 8:15 p. m. by President O. P. Chamberlain, with about 65 members and guests in attendance. There was no business before the Society, so the President introduced Mr. Paul P. Bird, M. W. S. E., Chief Smoke Inspector of the city, who presented his paper on Locomotive Smoke in Chicago.

Discussion followed from Messrs. F. A. Torry (C., B. & Q. Ry.), Wm. B. Jackson, H. T. Bentley (C. & N. W. Ry.), C. A. Seeley (C., R. I. & P. Ry.), J. F. De Voy (C., M. & St. P. Ry.), A. Bement, M. W. S. E.; R. W. Kuss, M. W. S. E. (Assistant Smoke Inspector); Albert Scheible, M. W. S. E.; P. M. Chamberlain, H. Misostom, W. A. Evans, Health Commissioner; H. H. Evans, M. W. S. E.; H. L. Harris, Smoke Inspector, the President, and a closure by Mr. Bird.

Meeting adjourned at 10:35 p. m.

J. H. WARDER, Secretary.

BOOK REVIEWS

THE AMERICAN CIVIL ENGINEERS POCKET BOOK. By Mansfield Merriam, Editor-in-Chief, and Twelve Associate Editors. New York, John Wiley & Sons. Leather; 4¼x7 in.; 1,380+viii pp.; profusely illustrated. Price, $5.00.

This book has been prepared under the supervision of Mansfield Merriam, well known to the profession as a professor, a consulting engineer, and a lucid writer of text-books on mechanics and hydraulics. He selected to aid him in the task a number of eminent engineers and professors of engineering, as follows: Mathematical Tables by Mansfield Merriam, 40 pages; Surveying, Geodesy and Railroad Location by Charles B. Breed, 102 pages; Roads and Railroads by Walter Loring Webb, 124 pages; Materials of Construction by Rudolph P. Miller, 132 pages; Plain and Reinforced Concrete by Frederick E. Turneaure, 88 pages; Masonry, Foundations, and Earthwork by Ira O. Baker, 78 pages; Masonry and Timber Structures by Walter J. Douglas, 126 pages; Steel Structures by Frank P. McKibben, 124 pages; Hydraulics, Pumping, and Water Power by Gardner S. Williams, 82 pages; Water Supply, Sewerage, and Irrigation by Allen Hazen, 108 pages; Dams, Aqueducts, Canals, Shafts, and Tunnels by Alfred Noble and Silas H. Woodward, 102 pages; Mathematics and Mechanics by Edward R. Maurer, 98 pages; Physics, Meteorology, Weights and Measures by Louis A. Fisher, 86 pages; Index by Clinton L. Bogert, 65 pages. The very complete index is by far the best part of the book and was evidently prepared by a young man who has good ideas of how he would like to have an index prepared to be really useful.

The men who are best fitted to prepare such pocket-books are men whose work is one year in hydraulics, the next in bridge design, a few months out of work, then a touch of building construction, with a few intermediate weeks or months spent in surveying. It is principally for such men that pocket-books are supposed to be prepared. A man wants to find in a pocket-book a *vade mecum* of short rules and full tables and information edging on that possessed by mechanics, whose work he is called upon to supervise. It should be in handy form and fit for quick reference. He often has to do a little drawing, and a few rules in practical geometry are useful to have at hand. This book is lacking in enough of this particular information, but it has 40 pages of a treatise on mathematics beginning with algebra and going into the calculus and higher curves. One may have to figure on a job of painting and looks into such a book to get mixing formulae and data as to the covering of surfaces, the best paint for certain purposes, etc. In the book under review he gets one page of a general description of paints, oils, pigments; something every engineer knows. In concrete work the designing portion is excellent but the practical part of the subject is treated in a cautious way that argues familiarity with the literature of the subject rather than the practical knowledge to be obtained by out of door experience.

The book as a whole is open to the criticism that it is prepared by men not actively engaged in engineering work in such a way that they need a book for quick reference. They are men who have good libraries close by and assistants to whom they can entrust the research work required when some problem troubles them. Few have ever been long enough engaged in the active practice of the profession in minor positions to have felt strongly the need of a good pocket-book for reference. The earlier editions of Trautwine were excellent because they were prepared by a busy engineer from the gleanings of a collection of data picked up in several decades of an active engineering practice in many lands.

The American Civil Engineers Pocket Book as an abridged treatise on civil engineering is excellent. On account of its marked text-book style it is adapted for class work in schools. It is deserving of a good sale but is not the best book to take into a camp where one book is all a man can carry with him. It is not complete enough for such a man in the most vital parts in which a pocket-book should be complete, and it contains much matter which may be considerably abridged. The book as it stands might be turned over to a board of engineering editors who never taught in schools but who want a good pocket-book; and these men will trim the book down to about two-thirds the number of pages and not omit a single essential fact, while much essential matter will be added. Nearly all the pocket (?) books now on the market in leather binding need much pruning and this book is no exception.

E. McC.

FOWLER'S MECHANICAL ENGINEERS' POCKET BOOK, 1911. 13th annual edition. 4 by 6 in.; 650 pages, illustrated; cloth bound. Price, 1s, 6d.

FOWLER'S ELECTRICAL ENGINEERS' POCKET BOOK, 1911. 11th annual edition. 4 by 6 in.; 570 pages, illustrated; cloth bound. Price, 1s, 6d.

FOWLER'S MECHANICS' AND MACHINISTS' POCKET BOOK, 1911. Cloth bound; 450 pages, 6d net. The Scientific Publishing Co., Manchester, England.

These three books are late editions of publications issued by the Scientific Publishing Co., Manchester, England, that have been noticed before in the pages of this publication. Considering the price—about 40 cents for either of the first two, and about one-third of that for the last of the list—they are wonderful books of their kind. The books are well printed and simply, but substantially bound, suitable for the tool-kit or pocket of an engineer or workingman. They contain many useful tables and formulae for ready use, and some good reading matter which is well illustrated when necessary to make the explanations clear and to be readily comprehended by the reader. Each book is provided with an extended index of its contents so that any matter between the covers can be easily found. There is necessarily some duplication of matter in the books, for the mechanical engineer needs some information of electricity and the electrical engineer would also look for information on subjects more specifically belonging to mechanical engineering.

The third book of this series, intended for use of mechanics and machinists, contains much of value and interest to men engaged in shopwork and which is not shown in the other books. One interesting subject which is of modern development is that of high-speed steel for cutting tools, and the editor has made a very valuable up-to-date presentation of this subject, with laudable quotations and presentations of the writings of Taylor and White, who first presented the results of their study and experiments to the American Society of Mechanical Engineers. Taken all-in-all the books, though plain and simple in general appearance, are valuable for their contents and any or all are a welcome addition to an engineering library.

W.

THE HISTORY OF THE TELEPHONE, by H. N. Casson. A. C. McClurg & Co., Chicago. 315 pages; 5½ by 8¼ in. Many half-tone engravings and copious index. Cloth; price, $1.50.

The Table of Contents, as follows, may give one some idea of this book: The Birth of the Telephone, The Building of the Business, The Holding of the Business, The Development of the Art, The Expansion of the Business, Notable Uses of the Telephone, The Telephone and National Efficiency, The Telephone in Foreign Countries, and finally, The Future of the Telephone.

It is a book of absorbing interest and is well worth reading. The author is strong in the story teller's art as was shown in another recent book of his, relating to Cyrus Hall McCormick and his invention and development of the harvesting machine. In this book is gathered a large amount of interesting material, woven together in an attractive manner. The title of the book nevertheless is to be deplored, as not being an exact statement of the case. It should have been modified to read, The History of the Bell Telephone Interests, from their point of view. Such a title would not have changed the interest of the subject and the manner of presentation and would have been a more honest statement. Some of the phases of telephony that should have been of great interest and importance to the real historian, have been swept aside as with a wave of a hand, leaving the impression that the Bell interests have a monopoly of telephone brains and virtue. A broader outlook, or a search for information not quite so close to the surface, would, with Mr. Casson's ability, have resulted in a more worthy book, as it is, though, very interesting and full of statements of interest, it produces too much of the effect of a special plea as presented by a corporation press bureau, and one is tempted to depreciate and minimize some of the heroics which really belong to the work and services of Prof. Bell and his associates. K. B. M.

THE CONSTRUCTION OF GRAPHICAL CHARTS. By John B. Peddle, Professor of Machine Design, Rose Polytechnic Institute, New York, N. Y. McGraw-Hill Book Company. Cloth; 6¼ by 9½ in.; pp. 109+viii; 58 illustrations in text. Price, $2.00.

Professor Peddle contributed a series of articles to the pages of The American Machinist on the construction of charts for graphical computation, and this book consists of a reprint of those articles. It is common these days to see in the pages of technical periodicals, descriptions of computing charts described by men who are using them in their daily work. It is also a matter of common occurrence to see charts, or graphical diagrams as they are generally called, hanging in the offices of designers and bearing evidence of use. That they are convenient is not doubted, and many men prefer diagrams to tables. Very little is known by the average technical man about the construction of such diagrams, and this book, therefore, meets a real want. Chapter I is devoted to the most common form, the rectangular co-ordinate system. Chapter 2 describes the alinement chart, which involves the idea of parallel co-ordinates, and the following chapter deals with the alinement chart for more than three variables. Chapter 4 takes up the hexagonal index chart, a modification of the preceding type. Chapter 5 describes a number of types of proportional charts, and Chapter 6 deals with empirical equations and methods for deriving such equations from graphs. The final chapter treats on stereographic charts and solid models. The simplest mathematical treatment is used throughout and the book is as useful to the veteran as to the newly graduated engineer. E. McC.

PRACTICAL ALLOYING. A compendium of alloys and processes for brass founders, metal-workers, and engineers, by John F. Buchanan. The Penton Publishing Co., Cleveland, Ohio, 1910. Full cloth; 6¼ by 9¼ in.; 205 pages, including index. Price, $2.50.

This is essentially a practical book written by one who is thoroughly familiar with the subject and who has a good command of the English language. Beginning with a chapter, Metal Refining—Ancient and Modern—the author next considers the History, Peculiarities, and Properties of Alloys. He then takes up Some of the Difficulties of Alloying, Methods of Making Alloys, Colors of Alloys, and Notation of Alloys. Standard Alloys and Foundry Mixtures follow and are succeeded by chapters on White Metals and Solders, Novelty Metals, etc. Fluxes for Alloys are next considered and in conclusion some practical instructions on moulding operations and about crucibles, are given.

The book contains some interesting illustrations and diagrams, also some valuable tables. The type work is good, clean, and pleasing to the eye, and the text is readable and instructive. The book should find its place, and one of importance, among those engaged in the practical working of alloys. It is eminently a book for practical use. W.

TESTING FOR METALLURGICAL PROCESSES. By James A. Barr, Engineer of Construction and Maintenance, formerly Instructor, Michigan College of Mines. First edition; cloth; 216 pages, 5¼ by 8¾ in., including index, with illustrations, diagrams, and tables. Mining and Scientific Press, San Francisco, 1910.

This work relates essentially to the examination of the ores of the precious metals and gives rules and processes by which the testing is done for the metallurgical process to be employed.

The opening pages relate to Amalgamation and Chlorination and describe the process of treatment of auriferous ores. Next follows Cyanidation, including preliminary investigations and chemical tests, with remarks on cyanide poisoning, etc. These instructions on cyanidation are amplified to include silver, copper, and associated baser metals. The subject of slags is one of much importance in many metallurgical operations and is considered quite fully in this work. Cost data are always of interest in the study of industrial operations and some pages are given to the consideration of costs of metallurgical operations. The matter is presented in a simple and readily understood manner and the book contains much of practical value. W.

LIBRARY NOTES

MISCELLANEOUS GIFTS.

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Engineering News Publishing Co., New York:
    The Art of Roadmaking. Harwood Frost. Cloth.
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Gen. G. M. Dodge, HON. M. W. S. E., Council Bluffs, Iowa:
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    Various reports of National Monetary Commission. Pam.
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Journal of the
Western Society of Engineers

VOL. XVI MARCH, 1911 No. 3

ENTROPY.

G. A. Goodenough.*

Presented Dec. 7, 1910.

What is entropy? is a question that cannot be answered unequivocally because the term entropy conveys different meanings to different people. The conception of the physicist and chemist differs from the conception of the engineer, and the confusion of these two different conceptions has led to much discussion. Furthermore, considering only the engineer's entropy, the doctors are not all agreed. According to one author, entropy is *heat weight;* according to another it is an *extensity factor;* a third calls it *the property of a body that remains constant during adiabatic expansion,* and so on. As a rule, text-books either neatly dodge the question altogether or give such imperfect and misleading definitions of entropy that the reader gains a distorted notion of this important physical function. Students, and possibly engineers, usually look upon entropy as something convenient to use in thermodynamic investigations, but in some way ghostly and mysterious and not to be understood by the intelligence of ordinary mortals.

Now there is nothing specially mysterious about entropy, and it is quite possible for one to gain perfectly clear-cut and definite conceptions of entropy. At the very outset, however, it is necessary to insist upon two essential points:

(1) There are two conceptions of entropy of which the second flows directly from the first. The broad conception of the physicist lies at the very foundation of physical chemistry. By the use of the entropy function, and other functions derived from it (the so-called thermodynamic potentials), problems in equilibrium are attacked and solved. A more restricted conception of entropy is used by the engineer in his attempt to represent by temperature-entropy diagrams the occurrences in the steam engine or gas engine. These two conceptions must not be confused.

(2) Entropy is frequently considered to be an intrinsic property of a body like its temperature, volume, color, or odor. Thus, entropy is defined as that property of a body which remains constant during an adiabatic change. To the vain groping for this alleged

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property, the futile attempts to obtain a mental picture of it, may be ascribed the feeling of mystery that seems to pervade the minds of students when entropy is mentioned. If we follow the development of the ablest of modern physicists, we shall find that it is only as a matter of convenience that we localize entropy in a body. Because, for the sake of convenience, we speak of the entropy of a body or the entropy of a system of bodies, it does not follow that entropy is a property in the sense that we ordinarily use the word property. This point will be further discussed after entropy has been defined.

The notion of entropy is bound up inextricably with one of the most important and far-reaching laws of physics, the so-called second law of thermodynamics. An explanation of this law is therefore essential.

Probably every educated man is familiar with the law of conservation of energy. As we know from experience, energy can be transformed, and is, in fact, being continually transformed in all the natural processes that come under our observation. The conservation law asserts that in all such transformations, the sum total remains the same—energy is neither lost nor gained. Another great law that has to do with energy-transformations is the *degradation law*. This, like the conservation law, is based on experience alone. It is even more evident from observation than the conservation law, but for some reason it seems to be relatively little known.

Let us consider somewhat closely certain energy-transformations, in particular the transformation of heat into mechanical work. It is an easy matter to transform work into heat, or electrical energy into heat. The reverse transformation, however, must be forced, so to speak; and we know from experience that only a fraction of a given supply of heat can be transformed into work—a fraction that unfortunately is very small. Let us denote by U the given amount of energy in any form, by A the part of this energy that can by any means be transformed into work, and by B the remainder. We may call A the *available part* of U, and B the *unavailable part*. We have, of course

$$U=A+B.$$

Now suppose any natural process to take place. According to the conservation law, the sum $A+B$ must remain constant; but the degradation law asserts that the result of the process is to decrease A and correspondingly increase B. The following are simple examples:

(1) Water in an elevated reservoir has a certain amount of energy available for doing work. The water of itself will seek a lower level where its available energy will be less.

(2) Heat of itself flows from a body of higher temperature to one of lower temperature. The quantity of heat is the same after the process as before, but the part of the heat available for work is decreased.

(3) A gas of itself flows from a region of high pressure to one of low pressure, as in blowing off a boiler. In the second state the gas has less energy available for work than in the first.

(4) Work is transformed into heat through a frictional process, as in churning water. It is impossible to reverse the process and recover the work expended. Only a small part of the heat generated can be transformed back into work, and there is consequently an irretrievable loss of mechanical energy.

We may now state the law of degradation of energy in the following terms: *In any natural (i. e., self-acting) change of state the available energy of the systems involved in the process is decreased.*

Directing attention to the special transformation of heat into work, we have next to devise a way of measuring the available part of a given quantity of heat Q, and the loss of availability or the degradation incurred as the result of a self-acting change of state. The ideal Carnot engine furnishes the desired means. As this engine is described in all the text-books, it is not necessary to go into details here. It is sufficient to recall Carnot's principle, namely: All reversible engines working between the same temperature limits have the same efficiency; that is, the efficiency is independent of the working substance and depends on the upper and lower temperatures only. The expression for this efficiency, as is well known, is

$$E = \frac{T - T_0}{T} = 1 - \frac{T_0}{T}$$

where T denotes the absolute temperature of the source of heat and T_0 that of the refrigerator. Given a quantity of heat Q in a body having the temperature T, then if T_0 be the absolute temperature of the coldest of surrounding objects, the part of Q that is possibly available for transformation into work is

$$A = Q\left[1 - \frac{T_0}{T}\right]$$

and the part that is unavailable is

$$B = Q - A = Q\frac{T_0}{T}$$

For various special processes the loss of available energy, or what is the same thing, the increase of unavailable energy, can be determined.

1. Let a quantity of heat Q flow from a body of temperature T_1 to a body of lower temperature T_2. Taking T_0 as the lowest available temperature, the unavailable part of Q at first was

$$B_1 = Q\frac{T_0}{T_1};$$

while in the second state it is

$$B_2 = Q\frac{T_0}{T_2}.$$

The increase of unavailable energy is therefore

$$B_2 - B_1 = Q\left[\frac{T_0}{T_2} - \frac{T_0}{T_1}\right]$$

$$\text{or} \qquad B_2 - B_1 = T_0\left[\frac{Q}{T_2} - \frac{Q}{T_1}\right] \qquad (1)$$

2. Let work be transformed into heat through friction as in churning a mass of water. Suppose T_1 to be the original and T_2 final temperature of the water, and Q the heat generated. Let $\triangle Q$ be a small element of heat generated at some intermediate temperature T. If we conceive this heat used in a Carnot engine, the part $\triangle A = \triangle Q\left(1 - \frac{T_0}{T}\right)$ could be retransformed into work; hence the net loss of work in thermal units is

$$\triangle B = \triangle Q - \triangle A = \triangle Q\frac{T_0}{T} = T_0\frac{\triangle Q}{T}.$$

The total loss of work is found by taking the sum of all the terms of the type $T_0\frac{\triangle Q}{T}$. Passing at once to the notation of integral calculus, we obtain

$$\text{Increase of } B = T_0\int_{T_1}^{T_2}\frac{dQ}{T}. \qquad (2)$$

It will be noted in equations (1) and (2) that the expression for the increase of unavailable energy has as one factor, the lowest available temperature T_0. Evidently, therefore, the lower we can make T_0, the smaller the loss due to irreversible self-acting changes. Since $B_2 - B_1$ is a quantity of heat, the other factor must, for the sake of consistent units, have the physical dimensions of the quotient $\frac{Q}{T}$. We find, in fact, that in one expression this factor is $\frac{Q}{T_2} - \frac{Q}{T_1}$, in the other $\int\frac{dQ}{T}$. If we take other processes, as for example the wire drawing of a gas, we find that in every case the increase of B

is given by the product of two factors, one of which is T_0, the other

$$\sum \frac{Q}{T} \text{ or } \int \frac{dQ}{T}.$$

To this second factor, which multiplied by T_0 gives the increase of unavailable energy resulting from a self-acting process, we give the name *increase of entropy*.

Thus, if we denote by B_1 the unavailable energy of a body or system of bodies in an initial state, and by B_2 the unavailable energy in the second state, we have:

$$\text{Increase of entropy} = \frac{B_2 - B_1}{T_0}$$

Let us now assume two numbers S_1 and S_2 defined by the relations

$$\frac{B_1}{T_0} = S_1, \quad \frac{B_2}{T_0} = S_2;$$

$$\text{then} \qquad \frac{B_2 - B_1}{T_0} = S_2 - S_1,$$

$$\text{or} \qquad S_2 - S_1 = \text{increase of entropy}.$$

For the sake of convenience, we associate the number S_1 with the initial state of the body or system and call it the entropy of the body or system in the initial state. Likewise we call S_2 the entropy of the body or system in the final state. Entropy, therefore, goes hand in hand with unavailable energy. An increase of the latter carries with it an increase of the former, and vice versa. Increase of entropy is proportional to increase of unavailable energy, the proportionality factor being $\frac{1}{T_0}$.

From this definition of entropy two important conclusions are at once derived:

(1) The energy of a body is purely relative, therefore the entropy is relative. It is not possible to assign an absolute value to the entropy of a body.

(2) The energy of a body is a function of the state only; that is, if a body—say a mass of air or steam—is made to undergo a series of changes and is finally returned to its initial state, the energy returns to its initial value. The unavailable part of the energy also assumes its initial value upon the completion of such a cycle of changes; and since the entropy is proportional to the unavailable part of the energy, it also returns to its initial value. Hence the entropy is a function of the state only. The change of entropy for a given change of state is fixed by the initial and final states, and is

in no way dependent upon the character of the process between those states.

The defining relation

$$B_2 - B_1 = T_0 (S_2 - S_1)$$

may be applied either to a system including a number of bodies or to a single one of these bodies. In the first place, let the system include every body that is in any way influenced by a given process. For example, if the process be heating water in a boiler, the system includes the water in the boiler, the shell, the hot gases, the setting, and the outside atmosphere, which receives heat by radiation. The system may therefore be regarded as isolated; that is, it neither receives energy from nor gives energy to surrounding bodies. According to the first law, the total energy of this system remains constant. According to the second law, the result of a change in the system is an increase in the unavailable energy B. This involves a corresponding increase of the entropy S.

We have therefore the following general principle which is often given as the second law of thermodynamics:

The entropy of an isolated system of bodies cannot decrease; a strictly reversible change in the system leaves the entropy unchanged, while a natural irreversible change is accompanied by an increase of entropy.

This principle is important in determining the *direction* of a physical (or chemical) change. A system if left to itself will change in such a way as to bring about an increase of entropy; and it settles into equilibrium when the entropy has reached a maximum value.

When we thus take as the system under consideration all the bodies concerned in a process, we are led to the broad conception of entropy so useful to the physicist and chemist in their researches on equilibrium.

Let us now restrict the system under consideration to a single one of the bodies taking part in a process. Thus if the process is the heating and evaporation of water in a boiler, let the system upon which attention is concentrated be a single pound of water. Evidently this system cannot be regarded as isolated,—it receives energy from other bodies and is influenced by surrounding conditions. Still adhering to the general definition of entropy given by equation (3), we inquire how the unavailable energy of this restricted system (say the pound of water) can be increased.

1. If heat Q be added to the system, the total energy of the system is increased by Q; therefore the unavailable energy is increased by the unavailable part of Q. If the heat be added at a constant temperature T, the increase of unavailable energy is

$$Q\frac{T_0}{T} = T_0 \frac{Q}{T}$$

but if, as is usually the case, the temperature changes during the heating, the increase is given by the expression

$$T_0 \int_{T_1}^{T_2} \frac{dQ}{T}$$

2. The system may receive heat as the result of irreversible conversion of work into heat. This case occurs in the flow of steam through nozzles, when there are eddy-currents, etc. Let H denote heat thus entering the system. Then as in the first case the increase of unavailable energy is $T_0 \int_{T_1}^{T_2} \frac{dH}{T}$

A special case of this second case is given by the wire drawing process.

3. The parts of the system may have different temperatures. Then the equalization of temperature results in an increase of unavailable energy. This we may denote by B^1.

The total increase of unavailable energy due to the three effects is the sum

$$B_2 - B_1 = T_0 \int_{T_1}^{T_2} \frac{dQ}{T} + T_0 \int_{T_1}^{T_2} \frac{dH}{T} + B^1$$

Hence by our definition, the increase of entropy is

$$S_2 - S_1 = \frac{B_2 - B_1}{T_0} = \int_{T_1}^{T_2} \frac{dQ}{T} + \int_{T_1}^{T_2} \frac{dH}{T} + S^1 \qquad (4)$$

$$\text{where} \qquad S^1 = \frac{B^1}{T_0}$$

If it be assumed that the temperature of the system is the same throughout, then the term S^1 disappears; and if further all internal frictional effects are absent, the term $\int \frac{dH}{T}$ disappears. Therefore for an ideal reversible process involving no friction, the increase of entropy is

$$S_2 - S_1 = \int_{T_1}^{T_2} \frac{dQ}{T} \qquad (5)$$

This relation is often given as the definition of entropy.

Evidently, as in the case of the isolated system, the entropy S of a single body depends only on the state of the body, and not in any way upon the process by which that state was reached. Hence we may couple the variable S with either of the variables p, v, or T, and the two together will completely define the state of the system. It is convenient for many purposes to take T and S as the variables and represent the change of state of the body under consideration by a curve on the TS-plane. Let AB, Fig. 1, be a curve that represents in this way the simultaneous values of T and S during a given change of state. From equation (5) we have the differential relation.

$$dS=\frac{dQ}{T},$$

whence

$$dQ=TdS,$$

and

$$Q=\int T\,dS, \tag{6}$$

The area of the elementary strip, Fig. 1, is TdS; it follows that the area A^1ABB^1 represent the integral TdS and therefore the heat Q absorbed by the body during the change of state from A to B along the curve AB.

The fact that the area under a curve on the TS-plane represents the heat absorbed by the body (provided all irreversible frictional effects are absent) makes the representation of changes of state on this plane specially useful in the study of the action of heat motors.

In thermodynamics, as in mechanics, we find it convenient and profitable to consider in the first instance purely ideal conditions. Thus in the analysis of the steam engine we choose an ideal cycle—usually the Rankine cycle; for the gas engine we choose either an ideal Otto cycle or an ideal Joule cycle. From these ideal conditions many far-reaching conclusions may be deduced, and these conclusions are generally not vitiated by the departure of the actual conditions from the ideal assumed conditions.

It is in the study of these ideal cases that we may freely and profitably use the temperature-entropy representation of changes of state. Since we are dealing with ideal conditions only, since our medium is supposedly at constant temperature throughout, and since the processes are all reversible and free from frictional effects, the relation given by equation (5) is valid, and the area under any curve on the TS-plane represents the heat entering the system.

It is hardly necessary to give in detail the representation on the TS-plane of various ideal changes of state and cycle processes. However, a few cases of special interest may be reviewed briefly. In Fig. 2, AB represents the heating of a body, as water in a boiler. The rise of temperature is represented by the increasing length of the ordinate, the heat absorbed by the area A^1ABB^1 swept over by the moving ordinate. The line EF parallel to the S-axis evidently represents a change of state at constant temperature that is an isothermal expansion. The line MN parallel to the T-axis represents an adiabatic compression, i. e., rise of temperature without addition of heat.

In Fig. 3, the four processes of the ideal Rankine cycle of the steam engine are shown. The heating of the water in the boiler is represented by *AB*, the vaporization by *BC*, the adiabatic expansion in the cylinder by *CD*, the condensation in the condenser by *DA*. Area A^1ABCC^1 represents the heat absorbed by the medium in the boiler, area C^1DAA^1 the heat rejected to the condenser, and the cycle area *ABCD* the heat transformed into work.

In Fig. 4 are shown the processes of the Otto cycle of the gas engine. *AB* represents the adiabatic compression of the charge, *BC* the heating at constant volume after the firing of the charge, *CD* the adiabatic expansion, and *DA* the cooling at constant volume back to the original state. With a change of scale, curves *BC* and *DA* may represent respectively heating and cooling at constant pressure, and *ABCD* then represents the Joule or Brayton cycle.

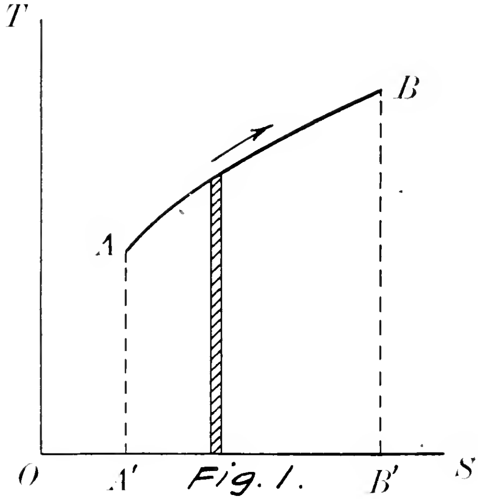


Fig. 1.

If traversed in reverse order, the figure *ABCD* represents the cycle of the air refrigerating machine; *DC* represents the adiabatic compression of the air in the compressor, *CB* the cooling of the air by the circulating water, *BA* adiabatic expansion in the expansion cylinder, and *AD* the heating of the air in passing through the cold brine. Area B^1ADC^1 represents the heat abstracted from the brine by the air, area C^1CBB^1 the heat dumped into the cooling water, and area *ADCB* the heat equivalent of the work that must be provided from an external source to drive the machine.

These examples are sufficient to show the utility and elegance of the method of representing ideal cycles on the temperature entropy plane. The method is of the greatest service in visualizing, so to speak, thermodynamic processes. The quantities of heat entering and leaving the system are represented by areas, the efficiency of a cycle is a ratio of areas and the effect upon the efficiency of various changes or modifications of the conditions is manifested at once by the changes in the areas. For the teacher of thermodynamics, this method is practically indispensable.

We have so far considered cases in which the increase of entropy is due solely to heat entering the system. Let us now take up the important case of heat generated within the system because of friction. If no heat is received from outside and the system at all times has uniform temperature throughout, then the terms $\int \frac{dQ}{T}$ and S^1 of equation (4) disappear and the increase of entropy is given by the expression

$$S_2-S_1=\int_{T_1}^{T_2}\frac{dH}{T} \qquad (7)$$

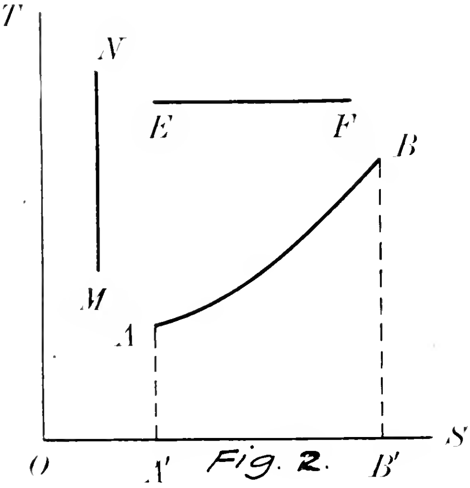


Fig. 2.

As explained previously, H denotes heat arising from the work expended on the system in overcoming frictional resistances. It may be observed that the change of entropy given by the equation (5) may be either an increase or a decrease; for dQ is negative when heat leaves the system and therefore S_2 is less than S_1. On the other hand, dH in equation (7) must inevitably be positive, and therefore the change of entropy given by (7) must always be an increase.

As a simple example of the application of (7) consider a mass of water churned by a paddle wheel, as in Joule's classic experiment. The quantity of heat H will be generated and the temperature of the water will rise. This process is represented by a curve similar to *AB,* Fig. 2, and the area A^1ABB^1 under the curve represents the heat *H*.

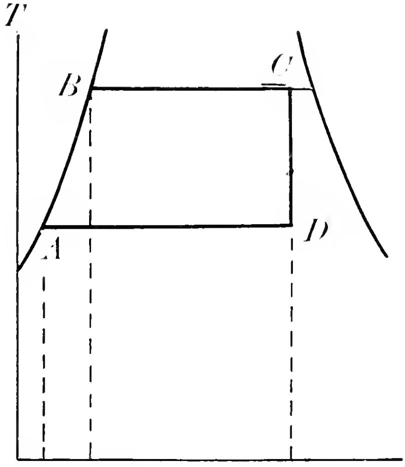


Fig. 3.

A familiar case is that of steam flowing through a nozzle. Let *A,* Fig. 5, represent the initial state of the mixture at the boiler pressure p_1. If the flow is adiabatic, as is usually assumed, then with no friction, the path representing the expansion to the back pressure

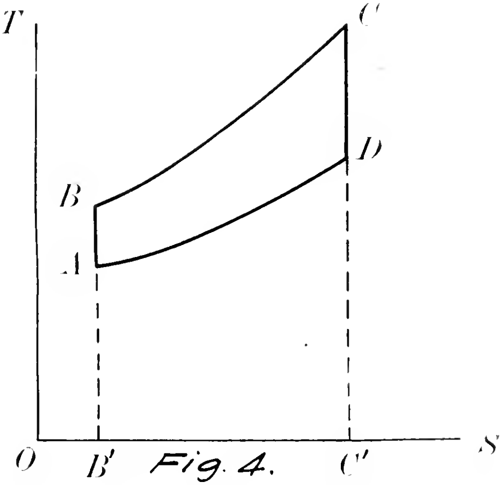


Fig. 4.

p_2 is the vertical line *AB*. As we know, however, the state indicated by point *B* cannot be attained; because of friction between the jet and the walls of the nozzle and internal friction due to eddies, etc., the steam receives heat during the expansion, though not from external sources. As a result the quality is increased and the final state is represented by point C lying to the right of point B. In this case the area under curve AC does *not* represent heat Q flowing into the system from external bodies, because $Q=0$. It *does* represent the heat H generated within the system.

When both effects are present,—that is, when the system receives heat from outside, and also heat generated within it through friction—the increase of entropy is evidently

$$S_2-S_1=\int_{T_1}^{T_2}\frac{dQ}{T}+\int_{T_1}^{T_2}\frac{dH}{T},$$

and the area under the TS-curve represents, not Q alone or H alone, but the sum $Q+H$. If our knowledge of the conditions were sufficiently complete, we might separate this sum into its components and say that so much of the area represents Q and the remainder H. But in actual cases such a procedure is quite out of the question.

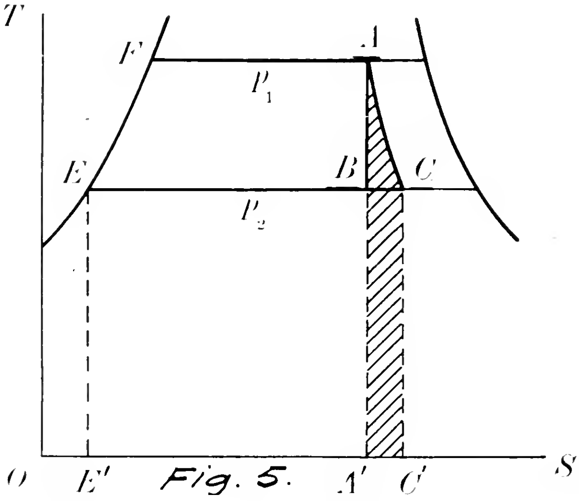


Fig. 5.

We are now in a position to consider a question of immediate practical interest; namely, the question of the validity of the temperature-entropy analysis when applied to actual working conditions. Of late years it has become quite the custom to subject tests of steam engines, gas engines, and heat motors of all sorts to such an analysis. From a steam engine test, for example, an average indicator diagram is chosen and from this a TS-diagram is plotted point by point. In thus plotting the diagram, one of several methods may be used, each giving a different result. From the diagram thus obtained, an attempt is made to determine by measurement the various heat-losses incurred during the cycle process. Now, provided all the processes represented by the indicator-diagram are strictly reversible and frictionless, there can be no doubt that such a procedure will give trustworthy results. But the processes are not thus reversible. During every part of the cycle, heat is flowing to bodies of lower temperature, there is a certain amount of friction and wire-drawing in the passages, and finally there is usually an irreversible drop of pressure when the exhaust port opens. As a result of these departures from ideal conditions, the entropy of the medium is increased independently of the heat entering it, and if the true values of the temperature and entropy are plotted, the area under the *TS*-curve represents something greater than the heat entering the medium. To show this point more clearly let us consider the two cycles *EFAB* and *EFAC,* of Fig. 5. In the first cycle, we assume the process *AB* to be reversible, and as shown in connection with Fig. 3, the area *EFAB* represents the heat transformed into useful work. The second cycle *EFAC* may be regarded as that of a steam turbine. The steam enters the turbine in the state *A,* but on account of the internal friction (through nozzles, blades, etc.), internal work is done, and as a result the final state is represented by *C* lying to the right of *B*. The area A^1ACC^1 represents the heat generated within the medium during the passage through the turbine. Does the cycle area *EFAC* represent the effective work obtainable from the turbine? Most clearly it does not; if it did, then it would be advantageous to have as much friction as possible. We have, in fact

$$Q_1 \text{ (heat absorbed)} = \text{area } E^1EFAA^1$$

$$Q_2 \text{ (heat rejected)} = C^1CEE^1$$

$$Q_1 - Q_2 = \text{area } EFAB - \text{area } A^1BCC^1$$

Thus the heat transformed into useful work is less than that indicated by the original cycle *EFAB.*

Since all the processes in any actual cycle are to some extent irreversible, it appears that the area of the cycle when plotted in temperature-entropy coordinates must be larger (for a direct cycle) than it should be to represent properly the heat changed into work. The magnitude of the difference depends, of course, upon the extent of the deviations from ideal conditions, i. e. the amount of wire-drawing, heat conduction, etc. Evidently, therefore, the *TS*-diagram cannot properly be used to give quantitative results. The measured areas do not accurately represent heat entering or leaving the medium, and the cycle area cannot be equivalent to the area of the indicator-diagram. To be sure a *TS*-diagram, if properly drawn, may give valuable information relative to the character of the losses in the cylinder, and it may be worth while to construct such diagrams merely for the information a comparison of them under different working conditions may give. The point to be emphasized is that it is worse than useless to attempt to get quantitative results by the direct measurements of areas.

In closing this discussion, we may revert to the question of the physical meaning of entropy. We have seen that entropy has a very definite and important physical meaning in its close association with unavailable energy. It is difficult to gain any further physical significance for it, and to conceive of it as a property, in the sense that temperature, volume, etc., are properties.

The entropy of a system, as has been shown, is dependent upon the state only and not upon the previous history of the system. Taking any two of the three variables, p, v, and T that define the state of a system as independent, we may therefore express the entropy S as a function of these two. Thus for a perfect gas, we have

$$S = c_v \log p + c_p \log v + S_o,$$

where c_v and c_p are specific heats and s_o is an arbitrary constant. If we choose v and T as the independent variables, we have

$$S = c_v \log T + (c_p—c_v) \log v + S^1_o.$$

We have here a function of the variables that define the state of the system of such a character that if the system is isolated the function can only increase, never decrease. This function is therefore a criterion for the possibility of a change in the system. So long as it is possible for S to increase, a change may occur; but when S reaches its maximum value, no further change is possible and the system is in equilibrium.

To throw more light on the nature of this entropy function, let us discuss a somewhat similar function that arises in mechanics. Taking, as usual, x, y, z as the position coordinates of a point, we may form an infinite number of functions of these three variables. One of these is the so-called potential function V. As is well known, a body of itself will move to a position of lower potential and will come to rest in a position of minimum potential. In other words, a mechanical system strives to attain a state of minimum potential energy just like a thermodynamic system strives to attain a state of maximum entropy. The potential energy of a body is merely a function of position. In its essential properties, a stone on a hillside is in no way different from the same stone after it has rolled down into the valley, though its potential energy is changed. A book lying on a table is not changed in any essential particular by being laid on a chair or on the floor. We would not think of using potential energy in the description of a stone or book.

It is precisely the same with entropy. We must look upon entropy merely as a function of the state of the system—one of many such functions that can be formed. It is a function that, applied to an isolated system, gives us information regarding the possibility of change and the direction of the change. It further gives a measure of the degradation of energy due to the change.

This may be regarded as the fundamental significance of entropy. While other physical interpretations have been suggested, they are more or less artificial and fanciful; furthermore they are unnecessary, and a hindrance rather than a help in a thorough understanding of a most important subject.

DISCUSSION.

President Chamberlain: I must confess that I do not feel competent, myself, to discuss this paper, as my knowledge of thermodynamics is confined very largely to a good many years ago when I went to college. Mr. Bement is with us this evening, and I believe he has some information which he can present. I will ask him to open the discussion.

A. Bement, M. W. S. E.: In opening the discussion, I will say that the Society has had more requests for a paper on entropy than any other subject, and we are indebted to Professor Goodenough for what is probably the best and most comprehensive treatment thus far published, although mathematical demonstration could have been supplemented by fuller explanation in the vernacular, to the very greatest advantage.

It might appear that the inquiry as to what is meant by entropy could be answered by a definition of the word. This is the usual course with words and terms which require explanation. Therefore, it may be of interest to present some definitions taken from various sources, which I do, as follows:

The Century Dictionary says, "(a) As used by Clausius, the inventor of the word, and others, that part of the energy of the system which cannot be converted into mechanical work without communication of heat to some other body, or change of volume. (b) As used by Tait and others, the available energy; that part of the energy which is not included under the entropy in sense (a)." And "The entropy of a system is the mechanical work it can perform without communication of heat, or alteration of its total volume, all transference of heat being performed by reversible engines. Clerk Maxwell, Heat, p. 186."

Webster's dictionary says, "A certain property of a body, expressed as a measurable quantity, such that when there is no communication of heat the quantity remains constant, but when heat enters or leaves the body the quantity increases or diminishes. If a small amount, h, of heat enters the body when its temperature is i in the thermodynamic scale, the entropy of the body is increased by $h \div i$. The entropy is regarded as measured from some standard temperature and pressure. Sometimes called the thermodynamic function."

Mr. James Swinburne in his book entitled, Entropy, or Thermodynamics from an Engineer's Standpoint, at page 125, gives the following as his definition of entropy:

> "The increase of entropy of an isolated system, multiplied by the lowest available temperature, is the incurred waste. The waste, therefore, depends on the lowest available temperature and the entropy. As any given change can only increase the lowest available temperature infinitesimally, the second and third laws may be stated in the form, 'The entropy of the universe strives to increase.' So does the waste. Its maximum will be reached when all heat is unavailable and there is no work left. The incurred waste increases faster than the entropy of the universe, because the lowest available temperature is always rising. The limiting expression 'incurred' is used before waste, advisedly. Suppose, in an isolated system, some gas expands doing some work external to the gas. The heat of the isolated system is diminished, the work increased, and the total energy unchanged. The heat being diminished without any corresponding rejection at lower temperature, the waste portion is decreased. There is thus actual decrease of waste. But, to get the gas back to its original state, work must be degraded into heat again, and, according to the third law, there is then increase of waste. Had the process been reversible, there would have been no increase of incurred waste in the system, but, as far as the gas alone is concerned, its own increase of entropy multiplied by the lowest available temperature would be the waste involved in bringing it back to its original state.
>
> "When during a change the entropy of a body forming a part of the system diminishes, the entropy of another part must increase to the same extent in an ideal change, and to a greater extent in a real change. In the ideal change the increase of entropy of the body is called compensated; in a real change the part of the increase equal to the corresponding decrease elsewhere is compensated entropy, Φ_c, and the balance is uncompensated entropy, Φ_u, where
>
> $$\Phi_u = \Phi - \int dH / \theta$$
>
> "When the heat of one body diminishes as that of another in contact with it increases, it is usual to say that the heat moves from one to the other. Similarly, when the entropy of one body diminishes while that of another in contact increases to the same or a greater extent, it is convenient to say the entropy moves and grows also. From the idea of the entropy of an isolated system and its increase in every change, it is easy to pass the idea of increase or decrease of the entropy of a body. In the case of reversibility the entropy of the isolated system is conservative, so that the discussion of the behavior of any body or bodies may be treated as in dynamics, by examining the changes and inter-relations of the external co-ordinates; and the conservation of entropy, in the ideal case of reversibility, is a very convenient assumption, especially as it specially helps the treatment as in dynamics, the conservation of entropy corresponding with the conservation of energy. The exaggeration of the importance of this treatment has done much to foster incomplete understanding of thermodynamics.
>
> "By treating the increase of entropy of an isolated system as the fundamental idea and variations of the entropies of the parts as derived ideas, it is submitted that a much clearer notion is obtained. It is more convenient, in practice, however, to consider the entropy of some substances or volumes which form parts of isolated systems."

About the time this definition of Mr. Swinburne's made its appearance, I was interested in an experiment which consisted in making inquiries of engineers as to what was meant by entropy. At the present time I cannot recall how many such inquiries were made, but the result was most interesting, as the only answer I obtained was from Mr. Walter T. Ray, who wrote me as follows:

Chicago, Feb. 11, 1905.

Mr. A. Bement,
Dear Sir:—

I write this letter in compliance with your request for my definition of "entropy."

Entropy is a ratio. It was noted by the early investigators of thermodynamics, especially Clausius, that they often came across the ratio:

$$\frac{\text{Changes in heat content.}}{\text{Absolute temperature at which the change occurred.}}$$

This ratio was later named entropy.

I shall take some examples, using a steam table. (I have Reeve's at hand.)

(1) Given 1 lb. of water at 212° F. under atmospheric pressure. Vaporize the water at constant pressure. It absorbs 965.4 B. T. U. (as seen in steam table column named Latent Heat of Vaporization). This absorption takes place at an absolute temperature of 672.8° F.

$$\frac{965.4}{672.8} = 1.439 \text{ ranks, as Perry names them.}$$

"Ranks" he gives as a name to the unit of entropy. The change of entropy in the above evaporization, we find to be 1.4349.

(2) Let us heat one pound of water from 32° F. to 212° F. According to steam table this requires 180.8 B. T. U.

The absolute temperature of 212° is 672.8°.
The absolute temperature of 32° is 492.8°.
The average absolute temperature is 582.8°.

$$\frac{180.8 \text{ B. T. U.}}{582.8} = 0.3102 \text{ ranks.}$$

Looking in the steam table on the 212° line in the column headed Entropy of the Water (above water at 32° F. which is given as 0.0000) we find 0.3126, which is more than 0.3102 by nearly 1%. This is because the temperature heat curve of water is not a straight line, because the specific heat varies. But this example serves to show the method.

Take a pound of saturated steam at 110 lb. gauge pressure; it has a total heat of 1186.4 B. T. U. according to ordinary steam tables, and a temperature of 804.8° F. absolute. Superheat it to 811° F. absolute and it will have a total heat of 1190 B. T. U. It has absorbed 3.7 B. T. U. in being superheated about 6°. The average temperature during this heating was

$$\frac{804.8 + 811°}{2} = 807.9° \text{ F. absolute.}$$

Number of ranks change in entropy=

$$\frac{\text{B. T. U. absorbed}}{\text{Average temperature during absorption.}} = \frac{3.7}{807.9} = .00458$$

I know of no table of entropies of superheated steam by which to check this calculation.

When a temperature-entropy diagram is plotted, the horizontal units are ranks; that is, B. T. U.'s exchanged.

$$\frac{}{\text{Temperature during change.}}$$

Often the average temperature during the change is not far wrong to use, but the process really ought to be taken by steps; that is, each little change in heat divided by the absolute temperature plus every other infinitely small change divided by its own absolute temperature. This constitutes an integration, which is an averaging by calculus.

Yours very truly,
(Signed) WALTER T. RAY.

In the *Engineering News,* Vol. 64, page 229, September 1, 1910, A. L. Menzin, under the title of The Physical Meaning of Entropy, gives a definition which, after having elaboration by William Kent, as explained in the issue of October 27, 1910, page 454 of the same volume, is as follows: "In the conversion of heat into work, entropy is the quotient, found by dividing the minimum avoidable waste, measured in heat units by the degrees of absolute temperature at which all of this waste may be rejected by the working substance." Kent also quotes Ripper, who in his publication on the Steam Engine states that, "Entropy is length on a diagram in which the area represents a quantity of heat and the ordinates represent absolute temperature."

We have in the foregoing what we must concede to be a sufficient difference in statement to show lack of definite agreement. This being a fact, I think it is time that we began to realize that the fault is not so much due, as the teachers would have us believe, to ignorance of the student, as it is to the fact that the matter is not well understood by the teachers themselves.

It appears to me that the trouble is due largely to what we may call the undeveloped conditions of the science of thermodynamics and that what we need is an examination of the problem from a much simpler standpoint than from which it is usually treated; less mathematics, clearer thinking and more common sense. I think, also, that much of the confusion is due to the fact that we lack a sufficiently developed vocabulary to give necessary accuracy of expression, and that the definition of terms now used are not well enough understood to insure that a definite and correct conception be had. Swinburne says, page 136, "The fact that the units in thermodynamics have no names, goes to show that the science is not fully developed. Measurement is an essential of science." And on page 137, "There is no unit of entropy. I would suggest the claus; a claus being the entropy which incurs a waste of one joule at a lowest available temperature of unity; e. g., if the lowest available temperature is 200 absolute, and the entropy is 10, the incurred waste is 2,000 joules."

I shall indulge in some unorthodox remarks to the extent of putting myself in a position of possibly being misunderstood by saying that one of our greatest troubles is, that the use of mathematics is very much overdone and that often their employment is a means by which an author obscures the fact of his lack of full understanding of a subject. I recall that an eminent member of this Society once said to me, that, when a person thoroughly understood a matter, he could explain it in very simple language. There is, of course, a certain danger in a person being candid and sincere, as in so doing he makes himself liable to misconception, and this fact is, in a measure, responsible for our difficulties, with the result that the student is put to much inconvenience and unnecessary labor. In this connection, I shall quote from Swinburne, because a statement of his is so significant. On page 111 of the above mentioned book, he says, in reference to putting things in plain language:

> "This is a very thankless attempt, for if one were to succeed in making a difficult subject appear clear and simple, the reader would think the subject itself easy, or that it has only been treated in a very elementary way, and very often that the writer's knowledge is also equally elementary, perhaps untrustworthy. The same subject treated in an involved way, with a quantity of obscure mathematics, is supposed to be more advanced and deeper, and to have much more in it.
>
> "Few realize that ease of reading varies inversely about as the square of easy writing, and if one seeks glory, the right thing is to make the subject as complicated and difficult as possible, and especially to use as many mathematical symbols as can be crowded in. It is quite the correct thing in science, after making calculations, to 'remove the scaffolding,' that is to say, to publish without giving the intermediate steps, so that others should think the feat greater." . . . . "If the treatment of a matter proves to be puzzling, the author is rather to be admired for being master of such a difficult subject, and not blamed for making it simple; whereas, if he put the matter simply and clearly, he would get but little credit for his work. This is especially true of subjects that can be treated mathematically; the scientific world has an immense reverence for anything put in mathematical language, though it needs much more ability and a clearer head to put it in words. Was it not Maxwell who said that mathematics is a shorthand, and that anything that can be put in symbols can be put in words, if the writer really understands it, and that nobody really understands unless he can express himself in words. Thermodynamics seems to be particularly unfortunate in being a vehicle for blind mathematics."

As a justification for my critical remarks regarding the use of mathematics, it may be well, in the way of explanation, and also as a justification for my position, to say that I uttered no such sentiments as these until after having made extended experiments with people to determine whether my ideas had foundation or not.

As illustrating the confusion and lack of clearness in the usual treatment of thermodynamics, the author, following the accepted reasoning, says the "potential energy of a body is merely a function of position." It would be nearer correct to say that the potential of the energy (of a body) is a function of position. The intimation that energy becomes changed in character or quantity without transformation into other forms is inconsistent. One of the fundamental teachings of thermodynamics is that energy cannot be changed or destroyed; that it can only be transformed. Thus, it is inconsistent to consider some energy as being potential and other as not, because such reasoning implies difference in quality. So if we have a quantity of heat in a body of air, which we wish to use for the purpose of warming a room, the temperature of which is 50°, while that of our warm air is 80, the potentiality of the energy is measured by the difference between the temperatures of 50 and 80. Now, if through some accident or otherwise before we can use our warm air, some cold air becomes mixed with it with the result that the temperature of the mixture is reduced to 60°, the heat in the original body of warm air is still present in the mixture of lower temperature. This quantity of heat is just the same; energy has not been changed in any manner, but potentiality has been altered. A B. T. U. at the temperature of 500° is no different than one at a temperature of 100°. There is, however, a difference in potentiality, or, in other words, its availability. With a stone of one pound weight held one foot above the ground, the potential of its energy is one foot pound, and at three feet above the ground the potential is three pounds, but if the stone is lying on the ground, the potential is zero and it is the same stone whatever the position, and what we have experienced is a difference in potential, not energy. Therefore, it appears necessary that we consider the terms potential and energy as distinct and separate, because energy cannot become changed without transformation, but potentiality (or, in other words, its opportunity, its power, its environment) may differ. From this we may see that the expression, degradation of energy, is a misleading one, as the meaning of the word degradation implies a deterioration, a change of character. It would be consistent to say that *potentiality* may be degraded. So with the stone which rolls down the hill-side from a lower point, as compared with a similar one which rolls from a higher point, there is no degradation, as it is precisely the same stone as though it had been started from the top of the hill. It would be accurate, however, to say that the distance from the top of the hill to the point from which it did roll is the measure of degradation of its *potentiality*.

As a further illustration of confusion, I would refer to the Journal of this Society, Vol. XIII, 1908, page 540, namely, the paper by Professor J. C. Thorpe, which is probably one of the best papers on the steam turbine that has been written. By experience and training as well as by education he was well qualified to present such a subject. On page 549, in discussing the matter of efficiency, there is a series of items which are listed under the head of energy losses, among which friction between steam and metallic surfaces; friction due to eddy currents; resistance to the motion of moving parts in the atmosphere of steam, were considered as losses of energy. Now we know, without question, that all of those processes resulted in the production of heat which was necessarily absorbed by the steam in the machine. This being true, there is no loss of energy.

In the discussion of Mr. Thorpe's paper, I stated on page 571 that "I think it unfortunate that as a general thing, there has been so little discussion of the factors which influence efficiency with turbines. After all, when the matter is summed up, it would appear that there are only three possible sources of loss, to wit:

(a) Heat in exhaust.
(b) Radiation from the exterior of the machine.
(c) Velocity in the exhaust."

I also stated that, strictly speaking, I did not think the other items should be considered as losses. This is a question which I had put in an experimental way to several engineers without a satisfactory answer, and, as a final move, tried it again in that form. It is interesting and significant of the general knowledge concerning these matters that Professor Thorpe did not reply to this question, but that it was answered by Professor Goodenough, who quoted the theory of the degradation of energy in reply.

At the nozzle of the turbine we have energy in the forms of velocity and heat, both of a high potential. In the process, however, a portion of this energy, instead of serving to turn the generator, is used in the production of certain frictional effects, the result of which is a generation of heat, which heat is necessarily communicated to the moving steam within the machine. Therefore, the result of this process is in no sense a loss of energy. What has occurred, however, has brought about a reduction in potential, so there has been a loss of potentiality. This, of course, causes a larger rejection of heat in the exhaust than there would be if it had not been for these frictional processes, and while we do not have a loss of energy therefrom, we have a loss of potentiality, which makes that energy less available. Therefore, these processes, instead of being losses, are causes which lead to losses. Now, it might at first appear that this reasoning is equivalent to "splitting hairs"—that so fine a distinction is not necessary—which, however, is not true if we are to have clear thinking and accurate understanding.

President Chamberlain: While Mr. Bement was speaking, I read over again the clause on the first page of this paper, "it is quite possible for one to gain perfectly clear-cut and definite conceptions of entropy." I suppose that some of us have come to that happy condition through the reading and discussion of the paper. I will say, though, that the definition given by Mr. Ray, the ratio of the heat added to the body—to the original temperature of the body—is something of which we can form a conception. Mr. Ray is ably supported by Webster's dictionary in that definition. I took the trouble to look the matter up today.

I am sure we would all like to hear from Mr. Abbott in regard to entropy, as he is one of our best-known mechanical engineers.

W. L. Abbott, M. W. S. E.: Putting together Mr. Bement's statement that none of us know anything about entropy, and the Chairman's suggestion that I have a reputation at stake, I conclude that I am about to lose something.

Entropy is a function and a property of heat, just as temperature is also a function and property of heat, and to get a conception of entropy it is first necessary that the conception of heat be clear and accurate.

Heat is the product of two factors—temperature and entropy. This also agrees with Mr. Ray's definition, that entropy equals total heat divided by absolute temperature. It is well known that unit weights of various substances respond variously in temperature rise to the application of heat. Then again, a substance, in passing from one form to another, as ice in changing into water or water changing into steam, absorbs a great quantity of heat without any increase in temperature at all. It is, therefore, apparent that the absorption of heat by a substance may be manifested in two ways—one a change in temperature and the other a change in another condition, which for designation has been called entropy, and any change in the quantity of heat of a body is accompanied by a change of one or both of the two functions whose product makes up heat.

Some of the mutual relations of the three functions discussed, viz., temperature, entropy and heat, may be shown by a diagram, which represents the change of state which ice, water, and steam undergo successively upon the application of heat, starting from a temperature of absolute zero, which corresponds to 460° on the Fahrenheit scale. Such a diagram is shown in the figure in which temperatures are represented along the vertical axis, entropy along the horizontal axis, and heat in B. T. U. is represented by areas. But because the temperature-entropy curve becomes tangent to the entropy axis at infinity, it is manifestly impossible to show on the diagram the origin of the curve. This condition is indicated on the diagram by a broken and discontinued curve, which I will ask you to imagine becomes tangent to the base line at a very remote point.

Let us assume one pound of ice at zero temperature. Its entropy will also be zero, because at zero temperature a substance is supposed to be absolutely devoid of heat. Now let heat be applied; the temperature will gradually rise to +32° F. As the specific heat of ice is .5, and as we have raised the one pound of ice through 492°, we have put into the mass 245 B. T. U. of heat. We must, therefore, represent this heat by an area having a vertical dimension corresponding to 492°, and such a horizontal dimension that the area enclosed between the curve and the base line will represent 245 thermal units. Such an area is shown in the triangular figure designated *A*, which has a temperature dimension ranging from 0° up to 490°, and although the entropy dimension is infinite in extent, the curve runs so near the base line that the included area up to 492° absolute amounts to only 246 B. T. U., assuming that the specific heat of ice averages .5 throughout the entire range.

After the temperature of the lump of ice under discussion has been raised to 32° F., further application of heat results in no increase of temperature until the ice is entirely melted; the heat absorbed during this process is, therefore, represented by a rectangle whose base is the zero line of absolute temperature, whose sides are vertical lines, and whose upper side is a horizontal line corresponding to the temperature of 492° Abs., or 32° on the Fahrenheit scale.

As the height of this second area, which is designated *B* in the diagram, is 492°, and as its area is 140 B. T. U.—the amount of heat necessary to melt one pound of ice—its horizontal dimension or entropy must be .28.

Let us continue to add heat to what is now one pound of water at 32° F. Unlike the melting ice, whose temperature remained constant during the application of heat, the temperature of the water will gradually rise. Let us assume that this water is being heated within a closed vessel, so that its pressure will run up to 220 lb. per sq. in. absolute, and its temperature to 390° F., corresponding to 850° Abs., and that the water which we started with at a temperature of 32° F. will still be water even at the high temperature. We have, during this change of temperature, added 363 B. T. U. at an average temperature of 200° F. or 660° Abs. and, therefore, the increase of entropy has been .55. The heat added during this period is represented on the diagram by area *C*.

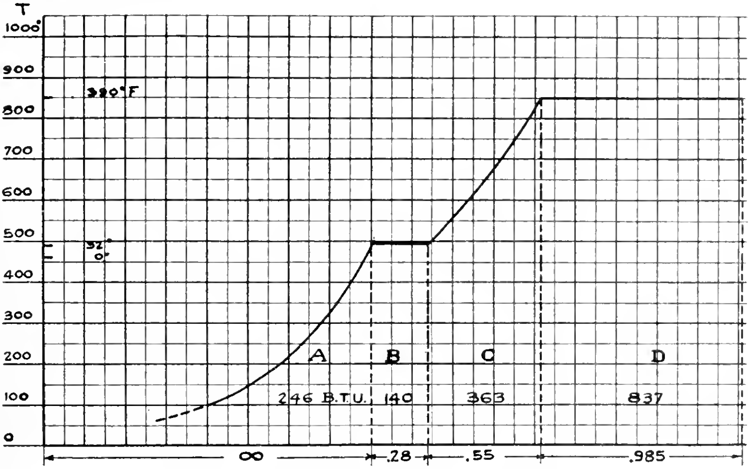


Diagram for W. L. Abbott's Discussion.

Let us assume that the closed vessel in which the water is being heated consists of a vertical cylinder fitted with a tight, frictionless piston weighted to 220 lb. per sq. in. With the further addition of heat, any increase of pressure will be relieved by the lifting of the piston. As there will be no increase of pressure, there can be no increase of temperature, and the absorption of heat will be accompanied by an increase of entropy only.

By referring to a steam table it will be seen that 837 B. T. U. will be necessary to convert the water at a temperature of 390° into steam. As the temperature is 850° Abs., and as the heat absorbed is 837 B. T. U., the increase of entropy will equal $\frac{837}{850}$=.985. This quantity of heat, with dimensions corresponding to .850° in temperature and .985° entropy, is represented by area *D*.

In steam tables, temperatures are measured in degrees, not from the zero of absolute temperature and not from the zero of the Fahrenheit thermometer, but from the temperature of melting ice. Likewise entropy is measured not from the point of absolute zero and not from the point where ice begins to melt, but from the point where it has just finished melting; and if we had some kind of a thermometer which would indicate entropy on some kind of a scale having its zero at that point, and if we were permitted to speak of degrees of entropy as we do of degrees of temperature, the whole subject would be much less befuddled.

To a mathematician the foregoing discussion may appear faulty, superficial and trifling; it may, nevertheless, serve to give the layman a conception of that intangible what, in the discussion of which great thermodynamicists belabor each other with Greek letters and integral signs.

I now resign the platform to the college professors present, who will proceed to show me up.

W. M. Wilson, M. W. S. E.: Of all the different conceptions of entropy which I have ever seen presented, the one which considers it as the extensity factor of heat is to me the clearest and most logical. This conception of entropy is presented by Sidney A. Reeve in his work on *The Thermodynamics of Heat Engines,* by showing by analogy the relation between heat energy and the other forms of energy with which we are familiar. Each of these different kinds of energy are made up of two factors, one of which is called the factor of intensity and the other the factor of extent. These are tabulated below.

Kind of Energy.	Factor of Intensity.	Factor of Extent.
Potential Energy of a Mass.	Height.	Mass.
Kinetic Energy of a Moving Mass.	Velocity.	Mass.
Potential Electric Energy.	Voltage	Charge.
Kinetic Electrical Energy.	Voltage	Current.
Chemical Energy.	Chemical Affinity.	Mass.

Reasoning by analogy from the above, since temperature is evidently the factor of intensity, entropy must be the factor of extent. This also agrees with the algebraic expression in which change in entropy is equal to the change in the quantity of heat divided by the absolute temperature at which the change occurs or change in entropy$=\frac{\Delta Q.}{T}$ That is, from algebra there apparently is a factor which, when multiplied by the absolute temperature, will give the quantity of heat, while from the analogy given above it is reasonable to suppose that there should be such a factor, and further that this factor is a factor pertaining to quantity such as mass, current, and charge rather than a factor pertaining to intensity such as height, velocity, voltage and chemical affinity.

To carry out the analogy still further, consider a mechanical device such as is shown in Fig. 6, in which there is shown a series of buckets suspended on an endless chain in such a way as to keep them in a vertical position at all times, except when they come to *B*, at which point they are inverted. Consider that a flume carrying water is placed so as to discharge into the buckets as they come to the position *A*. As the machine operates, water flows into the buckets at *A*, falls vertically to *B* and is then discharged. In nature the sun's rays complete the cycle by vaporizing the water and then allowing it to be precipitated in the form of rain or snow, when it falls upon the watershed and thence into the stream from which the flume leads. The cycle as outlined above is platted on a height-mass field in Fig. 7. Water flows into the bucket from *D* to *A* at constant height. The constant mass then falls vertically from *A* to *B*. At *B* the water is discharged at a constant height and then is eventually raised by nature or some other external means to its original height at *A*. During this cycle the working substance has done an amount of work represented by the enclosed area *ABCD*.

Consider now the case of a steam engine working on a Rankine cycle as represented in Fig. 8. Consider the water at the beginning of the cycle to have an entropy and temperature represented by the point *D*. Both the entropy and temperature increase along the curve until the point *A*, which is the point of vaporization, is reached. From *A* to *B* the temperature remains constant, while the entropy increases as the water is vaporized at constant pressure. From *B* to *C* the entropy remains constant and the temperature falls as the steam expands adiabatically. From *C* to *D* the temperature remains constant, while the entropy decreases as the steam condenses at constant pressure. The work done during the cycle is represented by the area *ABCD*.

The similarity of the two cycles represented in Figs. 3 and 4 of the author's paper, is apparent. The point which I have tried to bring out is that while entropy is not mass it does bear the same relation to heat energy that mass bears to potential mechanical energy, or that charge bears to potential electrical energy, or current to kinetic electrical energy. While this may seem to leave considrable yet to be desired in the way of a definition of entropy, we must remember that while mass is a term common to us all, yet it is one which evades satisfactory definition, and few of us would even attempt to define electric current or charge in such a way as to convey a physical conception of their meanings. Yet we use these terms intelligently and without confusion. I think that by holding the conception of entropy as set forth above, frequent handling of the factor will enable one to use it with intelligence and satisfaction.

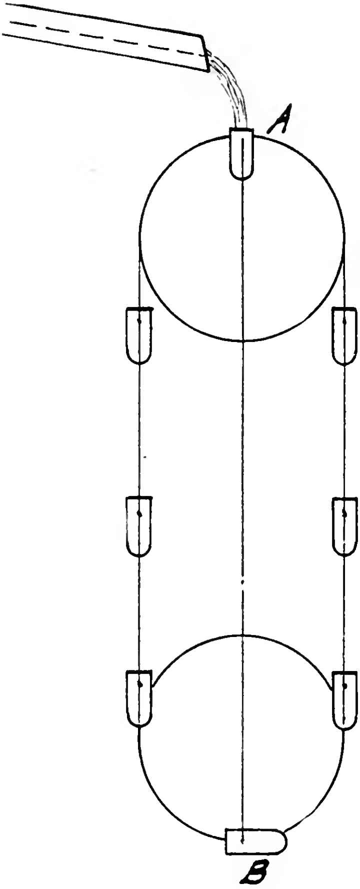


Fig. 6.

P. M. Chamberlain: It has been a pleasure to me to listen to the paper of Professor Goodenough and the discussions of Messrs. Bement, Abbott and Wilson. I am reminded that entropy was not discussed in my college course. As I mention this, I recall that the first use of the entropy diagram was by J. Willard Gibbs in 1873.

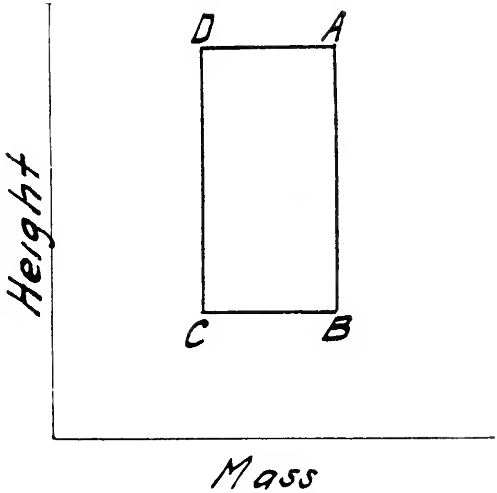


Fig. 7.

I am reminded every time I hear the word entropy of the dedication of Sidney A. Reeve's book on heat engines. He said, in addition to appreciative acknowledgment of devotion and inspiration, "This book is dedicated to my wife, though she doesn't know the difference between entropy and carbonic acid." There are many of us in position to sympathize with that condition.

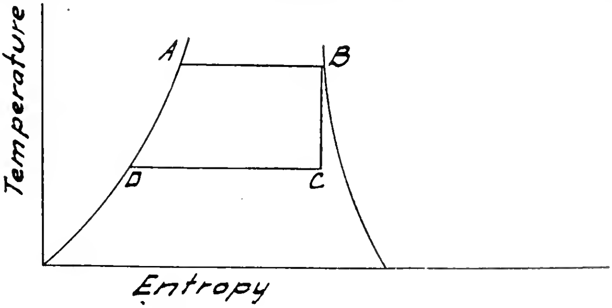


Fig 8.

The analogies presented to us by Mr. Wilson are very interesting, and, I think, if one starts early enough he perhaps can acquire a concrete conception. Entropy is a word which to me means simply the horizontal dimensions on the diagram. I have not a physical conception of it at all, any more than I have of the physical process that takes place in the extraction of the fourth root. The physical make up of the square and of the cube is clear, but when it gets to the fourth dimension, it is difficult to conceive.

The application of the entropy diagram to the steam-indicator diagram is very useful to the understanding of what takes place inside of the engine cylinder. Every one now understands the steam-indicator diagram, but I can remember when it was quite a wonderful thing to be able to analyze it. We had pressure indication and a line moving in a horizontal direction that represented the movement of the piston. The product did not at first mean much of anything, but it was the average height, and we finally got along to where we could think of this as representing the mean pressure throughout; then this multiplied by the distance through which it swept easily represented work or foot pounds. In the entropy diagram the area is a representation of heat units. We can get the physical conception of the vertical dimension of temperature. The heat units represented by area, divided by the vertical height, or temperature, gives a horizontal dimension, which we call entropy.

I have not the conception of a relationship between entropy and heat degradation that has been spoken of by the author. I appreciate that the tendency of all energy is to fall, but I have not gotten far enough along in the matter of entropy to grasp exactly what he means.

It may be remembered that a few years ago engineers spent considerable time in attempting to determine the amount of water used in the engine from the indicator diagram. As it was possible to get the horse-power from the diagram, some one thought it would be convenient to figure out the consumption of steam, and some quite ingenious analyses were arranged—excellent things for one to study—but we were no nearer the actual determination of water the engine had used when we got through than we were at the start.

Now the entropy diagram cannot be constructed directly from the indicator diagram. We must further determine the actual amount of water that passes through the cylinder, the clearance in the cylinder, the size of the cylinder and piston speed. We then have the data to construct the entropy diagram. If it follows the outline indicated by Mr. Abbott in the sketch, we would then have the Rankine cycle, as near perfect as it is conceivable for the steam engine to operate. There will be loss that is thrown to the atmosphere, but the action inside of the cylinder will be perfect.

Now by taking measurements on our indicator diagram we can find out how much volume there was in the cylinder at a given point; from the amount of water that went through the cylinder we can apportion the relationship, and from that mark off our points on the entropy diagram, tracing the movement of the heat from its entrance to its departure. The falling away from the diagram that we have already referred to in the sketch indicates where the heat has been absorbed where it ought not to have been, and where it is partially given out, when it should not be.

For instance, we know that in a steam-engine cylinder there is a great absorption of heat in the walls of the cylinder the moment the steam is admitted, and after the walls are warmed up, they give out some of the steam as it falls in temperature and expands. The result is that the heat is given back to the steam about the time it is ready to be exhausted to the atmosphere. The entropy diagram, carefully constructed, shows these movements and the extent of loss.

R. H. Kuss, M. W. S. E.: Never before has there been such a glorious chance to enter into the discussion of a paper before the Western Society of Engineers on equal terms with the authorities on the subject under discussion. All of the speakers here this evening have disclaimed any knowledge of the subject, and I, for one, do not propose to let the opportunity slip by without having something to say, which of course will be just as important and illuminating as the expressions that have gone before.

Some of the speakers seem to resent the fact that the author of the paper under discussion has seen fit to consider a subject beyond the depth of the so-called practical engineer. Because he has not tried to apply to entropy a significance which it cannot possibly possess, he must be condemned as a theorist upon whom we may not rely in the development of science in which mathematics play a part.

There are a great many things that need not have given to them special properties in order that they may be understandingly applied. We are constantly dealing with ratios, products, and quotients combining the dimensions of a substance which, when they recur often enough to be noticeable and useful, may be given names having more or less meaning, but to which no definite physical significance need or can be attached. Even the simple fraction obtainable from the steam tables known as "factor of evaporation," simply represents quantities which, being combined according to a constantly recurring method, called for the creation of the expression. The meaning of the ratio to which the term "factor of evaporation" has been applied cannot be enlarged to represent a property of the substance from which the quantitative items have been derived. No one would dare to hold, just because the term "factor of evaporation" has no special physical significance, that it is not useful.

There never has been anything mysterious to me about the term "entropy," so far as the fundamental meaning of it goes. I admit that the application of the ratio is somewhat more difficult. One of these difficulties arises from the fact that it is not profitable to attempt to create temperature-entropy diagrams, and tables for every conceivable mass of substance which may be dealt with. Consequently, those who have had to do with this matter have seen fit to make all of their entropy computations and diagrams on the basis of a mass of one pound. In the use of these diagrams it is necessary to convert mass quantities in the problem handled to the basis of the unit in which entropy plays a part. This makes it impossible to use a steam-engine diagram without change, inasmuch as it is necessary to reduce the engine diagram to fit a condition as though a mass of one pound of heat carrying medium were involved.

Mr. Bement attributes all of the darkness on the subject to undeveloped thermodynamics. To my mind this is not the difficulty. The trouble is that there is an undeveloped understanding of developed thermodynamics.

Mr. Bement: With reference to Mr. Abbott's remarks and the matter of the development of words and terms, we are relatively in the same position as are a primitive people with but limited vocabulary, who use one term to designate a variety of things, and the fact that the electrical people have improved their vocabulary by the invention of words and terms is, I think, one of the reasons why there has been such great development in the science and practice of electricity.

The electricians practically began their work since the teachers of thermodynamics took up the subject. Electricity is certainly as imponderable a matter as the science of thermodynamics, but while the teachers have been making slow and doubtful progress with it, the electricians made great advances. They are furnishing our light, running our street cars, factories, and are ready to run our railroads. They, too, have induced people to invest a few billion dollars in the electrical business. The fundamental reasons for this state of affairs is that the electricians have had an exacting taskmaster. They were necessarily responsible for the outcome of their efforts. They must make the wheels go round, and, if they did not do so, somebody else would be called upon to do it. The position of the teacher is different. Even if his efforts do not bear fruit in the pupil's mind, he may feel that he has done his part and be disposed to let the matter rest there.

In reference to Mr. Kuss's statement that he would attribute the difficulty to an undeveloped understanding of developed thermodynamics, this would, I think, be interpreted by the statement that as a general thing the treatment of thermodynamics, as usually presented, is not understandable, except to very few people, and with any person except the professional student of thermodynamics it is necessary that each study out the problem for himself rather than make use of explanation already available. This again brings up the question of the obligation of the professional teacher to the general public, which, in this instance, would mean the engineering profession. Reverting again to the matter of mathematical presentation, there is no ground for criticising an author if he uses mathematics to the greatest possible extent, if he is writing exclusively for people familiar with the symbols and expressions he employs, but when it is necessary for the reader to familiarize himself with the meaning of obscure (to him) symbols and treatment, or the application of formulae, he, in a very large majority of cases, has not either the time or the inclination to do so.

A. L. Menzin has written further on the subject, as published in the *Journal of Electricity, Power and Gas,* December 17, 1910, and thinking that it would be a useful contribution to the discussion of this important subject, it is quoted as follows:

> "Criticisms and comments on the physical meaning of entropy as advanced by me leads to but one conclusion—that I have not succeeded in explaining to others the simple physical significance of this term which I attempted to point out. Only the mathematical significance of my definition seems to have been considered: the physical significance seems to have been overlooked entirely. Probably this is due to the fact that the consensus of opinion at the present time seems to be that entropy has no physical meaning—that it is nothing more than the name which Clausius gave to the expression $\int \frac{dQ}{T}$
>
> "Since my first article attempts to point out what entropy really stands for in a physical sense, it seems necessary to re-develop the definition in the same way as it was developed originally, but with special emphasis on the physical significance of each step involved.
>
> "A clear understanding of thermodynamics, and of entropy, requires an appreciation of the fact that rejection of heat to an external substance, and therefore waste of heat, accompanies every practical attempt to obtain work from heat. In the gas engine and in the non-condensing and jet condensing steam engine the working substance is thrown away with the heat; in the steam engine employing a surface condenser only the heat is rejected, the working substance being retained for future use; in all heat motors heat is rejected in one way or another.
>
> "Carnot has shown that if a quantity of heat Q is absorbed by a working substance at a constant temperature T, and if the waste may be rejected at a constant temperature T_0 then the maximum work obtainable from the heat Q is $\frac{T - T_0}{T} Q$. The minimum waste is obviously
>
> $$Q - Q\,\frac{T - T_0}{T} = Q\,\frac{T_0}{T}$$
>
> "Now any conclusion based on the assumption that heat is absorbed at constant temperature would not necessarily be true when heat is absorbed at varying temperatures—a thermal condition characteristic of all working substances, particularly of the most common working substance of all—steam. In the process of making steam, the temperature of the feed water increases with the heat absorbed until steam temperature is reached, after which it remains constant during evaporation and then rises again during the period of superheating. Hence, in order that our definition of entropy may be broad enough to cover the actual working substances met with in practice, it should be based on the assumption that the temperature of the working substance varies during the whole or any part of the period of absorption.
>
> "Consider such a working substance, and the small amount of heat

dQ (equal to an infinitesimal in the limit) which is absorbed at any instant, and therefore at a practically constant temperature T. According to the Carnot principle the minimum amount of this heat which must be rejected is $\frac{T_0}{T}dQ$. If the unavoidable waste for each small amount of heat absorbed is $\frac{T_0}{T}dQ$, then the total unavoidable waste L for the total heat absorbed is therefore the summation of all the small elements of waste. Employing the calculus and assuming that the temperature at rejection remains constant, we have.

$$L = \int_0^Q \frac{T_0}{T} dQ = T_0 \int_0^Q \frac{dQ}{T} \text{ or } \frac{L}{T_0} = \int_0^Q \frac{dQ}{T}$$

"Now $\int_0^Q \frac{dQ}{T}$ is what is known as 'entropy,' and the physical meaning of its equivalent is interpreted as follows:

"In the conversion of heat into work, whether of heat external to a working substance or contained within it as intrinsic energy, entropy is the minimum unavoidable waste per degree of the absolute temperature at which all of this waste may be rejected by the working substance.

"It should be observed that I have not said that entropy is the minimum unavoidable waste divided by the absolute temperature at rejection; but that entropy is the minimum unavoidable waste per degree of the absolute temperature at rejection. The question is—has 'minimum unavoidable waste per degree of temperature at rejection' any physical meaning?

"That unavoidable waste is a perfectly familiar physical entity cannot be denied. We are conscious of it through the sense of sight and the sense of feeling. For what purpose is a condenser if not to abstract unavoidable waste heat? Temperature is likewise a perfectly familiar physical entity; and, since we know that the amount of heat rejected by an engine varies in some way with the temperature at rejection, why is not 'unavoidable waste per degree of temperature at rejection' a strikingly significant physical conception?

"Consider the analogy between velocity and entropy. Velocity is the ratio of two physical entities—distance and time; entropy is the ratio of two physical entities—rejected heat and absolute temperature; velocity determines distance passed over, and is itself determined by the motive power which produces it; entropy determines unavoidable waste, and is itself determined by the law of heat absorption. The fact that the velocity of an automobile is determined by the size of the engine is not an obstacle to our thinking of the velocity as the distance passed over per unit of time; the fact that the law of heat absorption $\int \frac{dQ}{T}$ determines entropy should therefore not prevent us from thinking of entropy as unavoidable waste per degree of temperature at rejection. There are two aspects for any physical property—the cause and the effect. What we know of most physical properties is through the effect. It is the same with entropy.

"A consideration of what has been said thus far might lead one to infer that this conception of entropy applies only to those limited cases where the state of the working substance passes through a complete cycle of change. A reference to the original article will disclose that this conception has a much wider application. In this article I have shown that in the process of obtaining work by degrading a substance from one thermal state to another, the minimum unavoidable waste per degree of temperature at rejection is the entropy of the heat required to restore the working substance to its initial state—this entropy, or relative waste, being independent of the path by which the substance attained its initial state and likewise independent of the path by which it attains its final state provided only that heat is rejected at some constant temperature. It is thus seen that the definition of entropy advanced is as applicable to the simplest of thermal changes as it is to the complex changes involved when work is done by a cyclical process.

"Consider the numerical value of $\int \frac{dQ}{T}$. It is determined by the amount of heat absorbed, which tends to produce a thermal change of state; and by the temperature during absorption, which is determined by the inherent characteristics of the substance, and is a factor in determining change of state for the heat absorbed. Entropy is therefore a function of the change of thermal state of a substance and, hence, a property of matter. From what has been said thus far it follows that—Entropy is that property of matter which determines the least amount of heat which must be rejected to an external substance during any change of thermal state. It is numerically equal to the summation of the quotients of the elements of heat required to reverse the change of state divided by the respective temperatures during absorption, that is $\int_0^Q \frac{dQ}{T}$. In a physical sense it represents the least amount of heat which must be rejected for each and every degree of the absolute temperature at rejection.

"Thus entropy, as a property of matter, is no more difficult to understand than velocity, specific heat, electrical capacity, electrical potential, and the numerous other physical conceptions concerning which there is no mystery. Assuming that the assumptions and mathematical processes employed in the development of this definition of entropy are valid, it is seen that there is no more 'ghostliness' about entropy than there is about any of the other terms just enumerated. It is a simple conceivable property of matter which enables us to appreciate the possibility of obtaining work from heat.

"To test our grasp of the physical significance of entropy let us consider a few problems.

"A pound of air is heated at atmospheric pressure from 100 to 200 degrees Fahrenheit. What does the change of entropy signify?

"It has been shown that change of unavoidable waste is associated with change of thermal state. An increase in the thermal state of a substance makes that substance liable to an additional increase in the amount of unavoidable waste—the relative increase is the 'change of entropy.' For the change of thermal state under consideration the change of entropy is

$$\int_0^Q \frac{dQ}{T} = \int_{T_1}^{T_2} C_p \frac{dT}{T} = C_p \log_e \frac{T_2}{T_1}$$

$$= .2375 \log_e \frac{200 + 459.5}{100 + 459.5} = .039 \text{ B. t. u.}$$

per degree Fahrenheit absolute, assuming that C_p, the specific heat at constant pressure, is constant, which is approximately true in practice. Thus an additional unavoidable waste of .039 B.t.u. per degree of absolute temperature at rejection is the result of heating the air to 200 degrees Fahrenheit. This must be incurred if the air is degraded back to its initial temperature, and will be the additional relative unavoidable waste if the air is degraded below this temperature, provided all waste is rejected at some constant temperature.

"Problems of more practical interest are the following: What is the minimum steam consumption and the maximum thermodynamic efficiency of an engine operating on dry steam at 165 pounds absolute running non-condensing? What would be the theoretical saving by running condensing, assuming a vacuum in the cylinder of 25.85 inches? Feed water will be taken at 180 degrees Fahrenheit in the first case and at 120 degrees Fahrenheit in the second case.

"It is not difficult to see that the most efficient way to utilize steam is by employing what is known as the Rankine cycle. In this cycle the working substance is initially water at exhaust temperature and pressure. The water is compressed to boiler pressure, heated to steam temperature, and evaporated into steam at this temperature. Adiabatic expansion then takes place until exhaust pressure is reached, after which the condenser abstracts the total heat of vaporization and returns the substance to its initial state as water at exhaust temperature and pressure. The work done is equal to the heat added minus the heat rejected. Since we must know the entropy to calculate the rejected heat, we must first develop the formula for the entropy of steam.

$$\text{Entropy} = \int_0^Q \frac{dQ}{T} = \int_0^{Q_1} \frac{dQ}{T} + \int_{Q_1}^{Q} \frac{dQ}{T_1}$$

$$= \int_0^{Q_1} \frac{dQ}{T} + \frac{Q - Q_1}{T_1} = \int_0^{Q_1} \frac{dQ}{T} + \frac{r}{T_1}$$

where r is the latent heat of vaporization, $\int_0^{Q_1} \frac{dQ}{T}$ is what is known as the 'entropy of liquid' and $\frac{r}{T_1}$ as 'entropy of vaporization.' The values of these expressions for different steam pressures have been calculated and tabulated by Peabody and others and hence are readily available for the solution of problems.

"In the Rankine cycle for the non-condensing steam engine, heat is employed to raise water from 212 degrees Fahrenheit to dry steam at 165 pounds absolute. The heat required per pound is 337.7 + 855.9 — 180.3, or 1013.3 B.t.u. The entropy is 0.5235 + 1.0370 — 0.3125, or 1.248 B.t.u. per degree Fahrenheit absolute. The absolute temperature at exhaust is 212 + 459.5, or 671.5 degrees Fahrenheit absolute.

"By definition, entropy is minimum waste per degree of exhaust temperature. Hence, if the waste per degree is 1.248 B.t.u., the total waste for 671.5 degrees is 671.5×1.248,, or 838.0 B.t.u. The work per pound is the difference between heat added and rejected, or 1013.3 — 838.0, or 175.3 B.t.u. Since one h.p. hour = 2545 B.t.u., this corresponds to a minimum steam consumption of $\frac{2345}{175.3}$, or 14.5 lb. per h.p. hour.

"For the condensing engine the working substance would be raised from water at 126.3 degrees to dry steam at 165 pounds absolute. The heat required is 337.7 + 855.9 — 94.3, or 1099.3 B.t.u. The entropy is 0.5235 + 1.0370 — 0.1756, or 1.3849 B.t.u. per degree Fahrenheit absolute. The absolute temperature at exhaust is 126.3 + 459.5, or 585.8 degrees Fahrenheit absolute. Since the entropy, or relative waste, is 1.3849 B.t.u. per degree, the total waste for 585.8 degrees is 585.8 × 1.3849, or 811.3 B.t.u. The total work per pound is, therefore, 1099.3 — 811.3, or 288.0 B.t.u.; and the maximum steam consumption is $\frac{2545}{288.0}$ or 8.8 lb. per i.h.p. hr.

"So far, the feed water temperatures have not been considered, since they affect only the heat (fuel) consumption and not the steam consumption. For the non-condensing engine with feed water available at 180 degrees Fahrenheit, the heat required is 337.7 + 855.9 — 148.0, or 1045.6 B. t. u. per lb. The work per pound according to the Rankine cycle is 175.3 B.t.u.; and the thermodynamic efficiency is $\frac{175.3}{1045.6}$ or 16.8 per cent.

"In the case of the condensing steam engine, feed water is available at 120 degrees Fahrenheit, and the total heat required is therefore 337.7 + 855.9 — 88.0, or 1105.6 B.t.u. per pound. The maximum work per pound is 288.0 B.t.u. and the thermodynamic efficiency is $\frac{288.0}{1105.3}$ or 26.2 per cent.

"The heat consumption per i.h.p. hour in the non-condensing engine is 14.5 × 1045.6, or 15,161 B.t.u. The heat consumption per i.h.p. hour for the condensing engine is 8.8 × 1105.6, or 9729 B.t.u. The theoretical saving by running condensing is therefore $\frac{15{,}161\text{-}9729}{15{,}161}$ or 35.9 per cent.

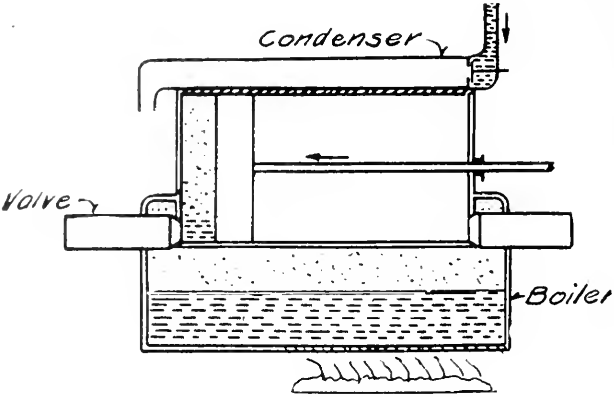
"The practical man may remark: Assuming that all this is so, of what use are the results since they hold only for the perfect steam engine? To the engineer and the conservationist they mean a good deal.

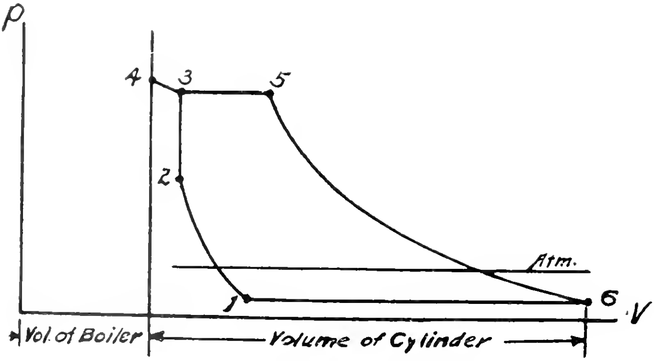
"We have just seen that the perfect condensing steam engine operating under practical conditions has a thermodynamic efficiency of 26.2 per cent. Assuming a furnace efficiency of 70 per cent, the efficiency of the perfect engine in terms of the fuel consumption would be .70 × 26.2 or 18.3 per cent. A good compound condensing steam engine plant will produce an i.h.p. hr. on about 15 pounds of steam at its most economical load. Since the ideal steam consumption is only 8.8 pounds, this plant is utilizing only $\frac{8.8}{15}$ or 58.6 per cent of the theoretical efficiency. The plant efficiency is therefore .183 × .586 or only 10.7 per cent—a rather striking example of actual waste. Herbert Spencer has said, 'Science is prevision.' The conception of entropy enables us to appreciate the imperfection of our present day power plants with eyes wide open.

"The student of theoretical thermodynamics may be interested in the accompanying sketch which shows a mechanical arrangement for a perfect steam engine and an indicator diagram supposedly taken therefrom. The diagram is the working cycle, and its efficiency is the ideal efficiency for the thermal changes involved.

"Strictly speaking, a complete engine consists of a boiler, working cylinder, condenser, air pump and feed pump. The engine itself may do the work of the feed pump and air pump as in the accompanying sketch. This is accomplished in practice by driving the feed and air pumps from the engine shaft. Clearance space exists for mechanical reasons only and need not be considered in the perfect engine. Of course the engine is assumed to be made of material which is a non-absorber of heat, and the condensing surface is supposed to be a transmitter only when in use; hence there can be no cylinder condensation or conduction of heat except to the condenser. Owing to the location of the condenser only one end of the cylinder can be used at one time but this can be done by employing a heavy fly-wheel.

"The operation is as follows: The initial position of the piston is as shown in the sketch, and is represented by 1 on the diagram. The condenser has just been cut out and the mixture of steam and vapor is about to be compressed. At point 2 the mixture has been compressed to water, and further compression compresses it to boiler pressure at 3 when the steam valve opens and the water is pushed into the boiler until the end of the stroke 4 is reached. The steam in the boiler expands and forces the piston back to the point 3, and from this point to the point 5 the water is heated to and evaporated at steam temperature. At 5 the valve shuts: The weight of steam in the cylinder is exactly equal to the weight of water originally injected into the boiler and the steam in the boiler is at its initial quality and pressure. Adiabatic expansion then takes place to 6 when the condenser is put into service and abstracts heat at a constant pressure and temperature until the initial state 1 is reached when the condenser is cut out and the cycle is repeated over and over again.





"For fixed steam and exhaust pressures the work done in this cycle may be varied by varying the compression, being greater or less according as the compression is greater or less. The heat required will be less

> as the compression is greater but, since it is more economical thermodynamically to use heat instead of work to raise temperature, the maximum thermodynamic efficiency will be obtained when there is no compression —in which case the cycle becomes identical with the Rankine cycle which has been employed in solving some of the above problems."

President Chamberlain: I believe that Mr. Bement's discussion and the definition by Mr. Ray, in conjunction with the diagram Mr. Abbott has made, has probably done more to clear up this matter with most of us than almost anything that has been presented or could have been presented. I think we all appreciate particularly the concise and clear way in which Mr. Abbott put the matter. I do not mean to say that we all know everything about entropy, but I can say for myself that I have learned a little something about it this evening that I did not know before, and have a different conception of it.

A. L. Menzin (by letter): I am much surprised to note the striking similarity between Professor Goodenough's treatment and my own as published in the *Engineering News* of September 1, 1910, which is apparent from the following abstracts.

Professor Goodenough's Paper.

1. Carnot efficiency$=\frac{T-To}{T}$

2. Unavailable heat$=B=Q\frac{To}{T}$

3. Loss for elementary quantity of heat$=To\frac{\Delta Q}{T}$

4. Total increase of loss$=To\int_{T_1}^{T_2}\frac{dQ}{T}$

From which follows the definition given on page 197 that "Increase of entropy is proportional to increase of unavailable energy, the proportionality factor being $\frac{1}{To}$"

My Paper Eng. News, Sept. 1, 1910.

1. Maximum work possible is $\frac{T-To}{T}Q$

2. Minimum waste is therefore $\frac{To}{T}Q$

3. For a small element of heat added the unavoidable waste is $\frac{To}{T}dQ$

4. And the total waste is $$To\int_{o}\frac{dQ}{T}=L$$

From which follows the definition that Entropy is the minimum unavoidable waste per degree of the absolute temperature at which heat is rejected.

The difference between these two treatments seems to be principally in the phraseology, and I am led to believe that the author had not seen my article, otherwise the similarity would have appealed to him immediately and would have caused him to make some comments thereon.

William Kent (by letter): The mystery about entropy is not inherent in the thing (or function) itself, it is in the attempted explanations of it. It is a pedagogical mystery why the writers of most of the text-books and other writers on the subject have so obscured entropy with words and with mathematical formulae, including differential equations, that the name entropy has become a terror to students. I taught classes in thermodynamics for five years, and never had any difficulty with entropy because I followed the definitions and methods given in Ripper's *Treatise on the Steam-Engine.* My pedagogical method may be explained as follows: First, the student should be familiar with the *pv* diagram of steam, gas, and air engines, and of the Carnot cycle, and he should understand isothermal and adiabatic expansion and compression and the formula, Efficiency = $(T_1 - T_2) \div T_1$ before he begins to study entropy. Then introduce it to him by giving him the simplest possible definitions, explain the definitions, and the temperature—entropy diagrams of the Carnot cycle and of water and steam. Show that entropy is merely a mathematical expression invented to save labor, similar to the moment of inertia, that it has no physical meaning, and that the diagram is a useful tool by which many thermodynamic problems may be solved more easily than by any other means.

Later, if desired, other definitions may be derived, as corollaries of those already learned, such as Swinburne's, that entropy is numerically equal to the quotient of the minimum unavoidable heat waste divided by the lowest available temperature. I do not think it advisable to take this as the fundamental definition. For a criticism of it, see Prof. W. F. Durand's paper in *Journal of Electricity, Power and Gas,* December 3, 1910.

The second law of thermodynamics may then be explained by means of the diagram, and different problems of reversible and irreversible cycles may then be taken up. It may then be shown that the elementary mathematical definition,

$$\text{increase of entropy} = \int_{T_1}^{T_2}\frac{dQ}{T}$$

applies only to reversible processes without friction, and the modifications of it made in irreversible processes may be shown, as they are in the paper.

The statements that entropy is relative, and that it is a function of the state of the body only, can easily be derived from the water and steam diagram without reference to the definition that entropy is the quotient of unavailable energy divided by the lowest available temperature, and I think a clear idea of entropy can be given in a more simple manner than that found on pages 2-5 of the paper. In fact, these pages would be made more clear if they were explained by temperature-entropy diagrams.

It may be of interest to quote here the writer's explanation of entropy given on page 573 of the 8th edition of his *Mechanical Engineers' Pocket-book.*

> "Entropy.—In the pv or pressure-volume diagram, energy exerted or expended is represented by an area the lines of which show the changes of the values of p and v. In the Carnot cycle these changes are shown by curved lines. If a given quantity of heat Q is added to a substance at a constant temperature, we may represent it by a rectangular area in which the temperature is represented by a vertical line, and the base is the quotient of the area divided by the length of the vertical line. To this quotient is given the name entropy. When the temperature at which the heat is added is not constant a more general definition is needed: *Entropy is length on a diagram the area of which represents a quantity of heat, and the height at any point represents absolute temperature.* The value of the increase of entropy is given in the language of calculus,
>
> $E=\int_{T_1}^{T_2}\frac{dQ}{T}$ which may be interpreted thus: increase of entropy between the temperatures T_2 and T_1 equals the summation of all the quotients arising by dividing each small quantity of heat added by the absolute temperature at which it is added. It is evident that if the several small quantities of heat added are equal, while the value of T constantly increases, the quotients are not equal, but are constantly decreasing. The diagram, called the temperature-entropy diagram, or the $\theta\ \phi$, theta-phi diagram, is one in which the abscissas, or horizontal distances, represent entropy, and vertical distances absolute temperature. The horizontal distances are measured from an arbitrary vertical line representing entropy at 32° F., and values of entropy are given as values beyond that point, while the temperatures are measured above absolute zero. Horizontal lines are isothermals; vertical lines adiabatics. The usefulness of entropy in thermodynamic studies is due to the fact that in many cases it simplifies calculations and makes it possible to use algebraic or graphical methods instead of the more difficult methods of the calculus."

The statement in paragraph 3, on the seventh page of the paper, that equalization of temperatures results in an increase of available energy, seems to require explanation, and it does not seem to be true in all cases. Suppose we have one pound of water at 800° absolute, to be added to one pound at 600°, assuming the lowest available temperature to be 500°, and the specific heat to be uniform. The available heat energy of the first pound is 300 heat units, and of the second pound 100; total 400. After mixing and equalizing the temperature, we will have two pounds at 700° absolute, each with

200 heat units available over 500°, or 400 heat units in all, showing no change of available energy. The unavailable energy and the entropy of the two pounds after mixing are also the same as those of the two separate pounds before mixing.

The remainder of the paper is a very clear and satisfactory explanation of the various subjects treated, and I think its clearness results from the frequent use of the temperature-entropy diagram which might have been introduced with advantage earlier in the paper. I am especially pleased with his showing that it is worse than useless to attempt to get quantitative results by the direct measurements of areas of temperature-entropy diagrams.

Sidney A. Reeve (by letter): Professor Goodenough's paper is to be commended as one of the clearest expositions of the subject of the conversion of heat into work, in so far as it bears upon the definition of entropy along orthodox lines, which I have seen. I find nothing to criticise in it as erroneous, except the sweeping and gratuitous conclusions which he draws in the early part of the paper, and in his closing paragraphs, and in the countenance everywhere given by inference to the old-fashioned idea of the degradation of energy—that temperature is everywhere decreasing, entropy everywhere increasing, and the energy of the universe steadily becoming less and less available.

These are conclusions only, however. Their error, as also the unsatisfactoriness of this entire orthodox method of treatment of the subject, is due to a foundation too narrow for the argument. The orthodox method consists in speaking of temperature as an abstract quality of a body, determinable by thermometry only. Heat is not only thus considered as an abstract quality, but *it is not even defined*. Nowhere in thermodynamic discussions can I find a definition of heat. It does not appear in this paper. Yet it is the first requisite. Energy, too, needs better definition.

From this narrow and abstract foundation there can naturally arise only a concept or definition of entropy which is abstract, mathematical and "ghostly and mysterious and not to be understood by the intelligence of ordinary mortals," as the author says. These aspects of heat, temperature, energy, and entropy are satisfactory to the professional physicist, because they admit of exact measurement and computation. They submit to scientific mathematical argument. But to the ordinary mind they must indeed remain unintelligible. It is *not* possible, as the author says, for such an one "to gain perfectly clear-cut and definite conceptions of entropy"—at least, along orthodox, abstract lines of reasoning.

Whether it is possible for the non-scientific to ever gain a working concept of entropy or not remains, in the broadest sense, to be proven. But there is this much hope for them. The ordinary mind, particularly of engineering training, sees the universe as a collection of definite solids separated by space. The ultra-technical, it is true, know that this is a false concept, that "solids" are not solid and that space is nowhere empty. Nevertheless, this is the boy's and the man's training. From the time he first bumps his nose to the the time he dissertates learnedly upon the trajectory of golf-balls before the club-house fire, he knows energy and intensity in terms of solid mass, empty space, visible motion, and perceptible force.

Now, this equipment as a basis for the study of heat, temperature, work, and entropy proves to be not an unscientific one, after all. It is now over two centuries since Newton gave us our first exact definition of force in terms of mass, space, and motion. It is now over a century since modern science revived, in the chemical studies of men of the Dalton and Avogadro school, the ancient Greek concept of all matters as made up of distinct and moving "indivisibles," or "atoms." It is over a century since heat was investigated as a form of mechanical motion of mass by Count Rumford. It is a full generation since Lord Kelvin showed that the true measure, and therefore, the true identity, of temperature was not *heat,* measurable by thermometry, but *work,* measurable mechanically. Hence, what we call our "heat-engines" are not truly such, but should be known as "temperature-engines" instead. They do not convert heat into work. They merely withdraw from the heat its work-dimension, temperature, leaving its heat-dimension, or entropy, unchanged.

Therefore, the natural query, upon reading such a paper as this is, why ignore all this accumulation of scientific knowledge in our attempts to define or conceive entropy? If we start off frankly with no ammunition other than mass, space, and motion we are fully equipped for a clear, mechanical concept of (1) force; (2) energy—a clear concept of which in its mechanical form is the greatest lack in our present engineering curriculums; (3) heat, and (4) temperature.

These concepts then necessarily appear not as qualities of matter, or mass, but as qualities of relatively *between* mass-portions. This first throws not only heat, etc., but mass also, first into its true light. Mass now appears plainly as devoid of all quality. It possesses—it is—*quantity* only. It is merely our exact definition of quantity of matter. All *qualities* of matter, whether heat, temperature, elasticity, color, chemical or electrical attributes, or what not, then appear plainly as peculiar to spacial and kinetic relationships *between* mass and mass. They exist only where mass is not.

From this simple start, the path properly pursued brings us to a similar definition and concept of entropy, not as a mathematical formula but as a feature of mass grouped in distinct, solid, inert, quality-less portions separated by space and motion. Entropy then appears plainly as the same part of heat that mass is of mechanical energy. Any mind which can understand mass can understand entropy. If one can understand the difference between hitting a baseball squarely for a straight drive through the pitcher's box, and giving it a foul tip that sends it spinning without translational energy, he can understand fully and clearly the difference between the efficiency of adiabatic work-performance in heat-engines and the inefficient increase of entropy by free fall of heat down-temperature.

This concept of heat, entropy, etc., has not as yet been reduced to the same convenience and exactness of mathematical treatment in laboratory and college as the orthodox concept. We are waiting for a second Clerk Maxwell to do that. Therefore, its acceptance in college is slow and reluctant. But it is a vastly more useful concept than the orthodox for teaching young men who wish to be engineers, not scientists, a working grasp of the principles of thermodynamic engineering.

The limits of a discussion of a technical paper, of course, preclude any excursion into the details of the argument just outlined. Any curious about them will find them in my book on "Energy." Those who follow its reasoning will find themselves at issue with the author in the first paragraph on page 206 and the last paragraph on the same page. Not only has entropy "a very definite and important physical meaning in its close association with unavilable energy," but it is *not,* as he says, "difficult to gain any further physical significance for it, and to conceive it as a property, in the sense that temperature, volume, etc., are properties." They will find that there are not only some people who do "think of using potential energy in the description of a stone or a book," but that when this is done, and the true difference between a book lying on a table and one lying on a chair or the floor is understood, a great many wonderful and beautiful vistas in the understanding of universal law are opened before one, where blank walls or impenetrable thickets blocked and discouraged before.

CLOSURE.

The Author: The discussion of this paper has been a great surprise to me, in the first place because of its volume, and secondly because certain points that I specially emphasized with a view to provoking discussion were not mentioned, while other questions that I considered practically settled and that I dismissed with scant attention received the brunt of the attack.

Before replying to the various criticisms offered, I wish to call attention to the recent book by Professor Klein. The Physical Significance of Entropy. Had I read this book before writing the paper, I would perhaps have modified certain statements in the paper, or better I might have suppressed the paper entirely and referred the Society to Professor Klein's work as the most adequate presentation of the subject that has yet appeared.

The propriety of basing the definition of entropy on the degradation law is questioned. Previous to the famous controversy between Swinburne and John Perry in 1903, and the appearance of Swinburne's book, Entropy, it was not customary to connect entropy so closely with the degradation of energy. To be sure, the physicists and chemists following Gibbs, were making great use of the principle of increase of entropy as the integral $\int \frac{dQ}{T}$ Swinburne performed a real service in calling attention in a most vigorous way to the misleading conceptions that must necessarily result from a strict adherence to the old definition. The connection between entropy and degradation of energy did not of course originate with Swinburne. Preston's Theory of Heat (1894) contains a most clear presentation in the chapter entitled Entropy and Available Energy. Bryan, who must be considered one of our highest authorities on thermodynamics, bases his whole treatment of thermodynamics squarely on the laws of conservation and degradation. In his chapter VII, he introduces two definitions of entropy, the first being the time-honored integral $\int \frac{dQ}{T}$, and the second the unavailable energy divided by T_0. Commenting on these definitions, he says, "In dealing with reversible phenomena, it (the first) leads to consistent results and is sufficient. But there are many irreversible phenomena, for which this definition is inapplicable or can only be made applicable by somewhat cumbersome extensions. It is in many ways unsatisfactory or at least inconvenient. The second definition makes no restrictions as to the nature of the transformations which take place; it holds if the unavailable energy is imported into the system in the form of heat received from without, as well as when irreversible changes occur in the system itself, producing an increase of unavailable at the expense of available energy."

It is held by Mr. Kent and others that even if we eventually explain entropy in terms of degradation of energy, it is best from the pedagogic point of view to define entropy at first as $\frac{Q}{T}$ or $\int \frac{dQ}{T}$ In most cases I agree that it is usually better to start with the simplest conceptions and gradually work up to those more difficult or abstruse. There are cases, however, in which this procedure is nothing short of criminal. A shining example is presented by the orthodox treatment of motion in mechanics. Rectilinear motion is discussed first because it is simpler than curvilinear motion. The student gets the conception of acceleration as rate of change of speed without reference to direction, and this notion gets so firmly fixed that nothing short of a surgical operation will convince him that a point moving in a curve has an acceleration even if the speed is constant. All this trouble can be obviated by taking up the most general case at the start. The definition of entropy presents a similar problem. If we start with the definition suggested by Mr. Kent, that entropy is merely a horizontal distance on a diagram in which T is the ordinate and Q is the area under curve (this is essentially defining entropy as $\int \frac{dQ}{T}$), we have trouble ever afterward. The student gets it firmly in his mind that an area on the TS-plane always represents Q. We caution him that this is only the fact when the process is reversible, and point out that otherwise it is not true. Then we must tell him some time or other that reversible processes are merely ideal abstractions, and that, as a matter of fact, any actual process is irreversible; consequently we must apologize for our definition of entropy and acknowledge that accurately it does not hold good for any change that occurs in nature. By this time the student's mind is delightfully clear (?) regarding the whole subject. On this point I write from experience. If, on the other hand, we start squarely with the definition that increase of entropy is proportional to the increase of the unavailable energy of the system, we at once arrive by easy steps at the defining relation

$$S_2 - S_1 = \int_1^2 \frac{dQ}{T} + \int_1^2 \frac{dH}{T}.$$

We can then take as a special case the absorption of heat Q from outside, in which case the change of entropy is $\int_1^2 \frac{dQ}{T}$ alone, or we can with equal facility consider the case in which heat H is generated within the system as in the flow of fluids and in the steam turbine. In this case the increase of entropy is $\int_1^2 \frac{dH}{T}$ alone. By starting thus we have no cautions to give, no apologies to make at any stage, and we are not burdened by the necessity of making the student unlearn this week what we taught him last.

We will all agree that Mr. Abbott's reputation has not suffered by his presentation of the subject. The objection to the definition by Mr. Ray, which he explains, is the one that I have just discussed, namely, that it fails completely when we take up such problems as the flow of steam, the friction in turbines, and the irreversible flow of ammonia through the expansion valve in the refrigerating machine. It is unfortunate that we have no name for the unit of entropy; but I do not see that if we had a name we would be any further along in a real understanding of the nature of this elusive function.

I read Mr. Menzin's article in the *Engineering News* and I must acknowledge that the similarity between his treatment and mine did not impress me at all. Of course, the similarity exists; how could it be otherwise? If we both base the definition of entropy on the degradation law, we must necessarily obtain the same equations. If Mr. Menzin thinks he has contributed anything new, as he evidently must, I call his attention to Chapter VII of Bryan's Thermodynamics (1907) where the whole subject is discussed much more completely than in his paper or mine, and the equations deduced are precisely the same. As a matter of fact, I was giving this treatment of the second law to my classes five years ago, before the appearance of Bryan's book; hence I have seen no necessity of acknowledging an obligation either to Bryan or to Mr. Menzin.

In reply to Mr. Bement's criticism, I may say in the first place that there is, no doubt, much difference of opinion regarding the significance of the laws of thermodynamics. It could scarcely be otherwise. Thermodynamics is a very fundamental and far-reaching science, and is undeveloped in the same sense that biology is undeveloped. Just as learned men dispute about the doctrine of evolution, so may they naturally hold different views regarding the foundations of thermodynamics.

Mr. Bement wishes me to say in few words and without mathematics just what entropy is. I reply that I cannot do it because, as I stated in the first sentence of the paper, entropy means different things to different people. I have tried to give my conception of entropy as a factor of unavailable energy. I have not the genius to do this without introducing various symbols and mathematical expressions which, however, are simple and ought to be intelligible to the engineer. Another may have a different conception of entropy (it is quite evident that Mr. Reeve has), and his conception may be preferable to mine.

In this connection, I wish to emphasize a point made in the paper that has not been mentioned in the discussion. The physicists and chemists, at least since the appearance of Gibb's monumental work, have had no difficulty with entropy and have made it the basis of fruitful investigations. The chemist has a heterogeneous mixture of liquids, solids partly in solution, and perhaps the vapors of some of the liquids. He is able to calculate the entropy of the entire system relative to an arbitrary zero. He then finds (by calculation) the kind of change that will result in an increase of entropy, and he knows absolutely that this is the change that will occur if the mixture is left to itself. The chemist thus uses entropy as a function of the state of his system that points out the *direction* of a natural change. As Planck aptly says: *"There exists in*

Nature a quantity which changes always in the same sense in all natural processes." This is what entropy means to the chemist. The engineer never makes use of this conception. He never deals with isolated systems but directs his attention to a single component of the system, as a pound of steam in a boiler, or the air in a cylinder of a gas engine. Herein lies a possible source of confusion. As I tried to show, we can adhere to the broad conception of entropy used by the physicists and still get a consistent definition of the entropy of this smaller system to which we direct our attention. When we do this, we arrive at equation (4) of the paper. The use we engineers make of entropy, thus restricted, is not at all the use made of it by the chemist. We couple entropy with temperature and draw diagrams showing the course of events in a heat motor. Increase of entropy of a pound of water does not necessarily involve any degradation of energy, and it does not indicate the direction of a process.

I cannot agree with Mr. Bement that the teachers of thermodynamics are hopelessly befuddled, and the difficulty lies in the teaching rather than in the student or in the subject. There is no doubt whatever that thermodynamics is a difficult and abstruse subject and that its principles cannot be mastered without good hard thinking. The demand is insistent at the present time that we teachers give our students a diet of pleasant sugar-coated, predigested food, without any bitter flavor of mathematics. Such a diet is, of course, pleasant for the student but it is not very strengthening. In Mr. Bement's remarks upon teaching and upon mathematics, I think I see a dim reflection of this modern tendency.

Regarding Mr. Bement's rather fine distinction between potential energy and the potential of the energy, and his discussion of turbine losses, I dare say he is right. We are not usually accustomed to such extreme accuracy. If I should accidentally drop my pocketbook over the rail into Lake Michigan, I would say in vulgar parlance that I had lost some money. Mr. Bement would say more accurately that I had not lost money but rather the potentiality or the purchasing power of the money.

The last sentence of Mr. Kent's discussion is of special interest to me. I had expected that my statement as to the uselessness of the TS-diagram for the purpose of measurement would be vigorously disputed.

Mr. Wilson's communication illustrates my earlier statement as to the number of different conceptions of entropy that are possible. I was once quite fascinated by the conception set forth by Mr. Wilson of entropy as a factor of energy. The series of analogies makes this conception peculiarly plausible and attractive. The trouble with this notion of entropy is that it is of service only in reversible processes of the kind Mr. Wilson has used in his illustration. Attempt to apply it to the flow of steam through a nozzle and troubles arise thick and fast. Swinburne very effectually disposes of this conception in his book 'Entropy," page 66.

In reply to Mr. Reeve's criticism, I agree that probably my statements regarding the physical interpretation of entropy were too sweeping and dogmatic. I shall persist, however, in being old-fashioned to the extent of countenancing the doctrine of degradation of energy. While I have great respect and admiration for the brilliancy and originality of Mr. Reeve's speculations, I am not yet thoroughly convinced of their soundness, and for the present at least I shall remain with the orthodox.

In closing this somewhat lengthy discussion, I cannot refrain from indicating briefly the interpretation of entropy given by Professor Klein. Mr. Bement has urged me to do so and he must therefore be held partly responsible for this addition to the original paper.

Professor Klein's book is an exposition of the methods of Boltzmann and Planck. The essential feature of Boltzmann's work is the recognition of a statistical nature of certain physical phenomena and the appliction of the laws of probability to these phenomena. Heat is considered as molecular motion of the most disordered, haphazard character possible. The multitude of particles that compose a given volume of gas are moving in all directions with all possible velocities. For any particle at any instant, all directions are equally possible, therefore equally probable. This disordered motion that characterizes heat energy may be contrasted with constrained or ordered motion of the kind we consider in mechanics. It is observed as a universal law that ordered motion tends always to degenerate into disordered motion. Thus, in a sound wave, the air particles have to a certain extent ordered motion, but gradually this changes to disordered motion, that is, the energy of sound is transformed into heat energy. Boltzmann introduces the notion of the probability of a state of a system. The probability, for example, of a gas having its molecules all moving in one direction so that pressure would be exerted only on two walls of the containing vessel, is very small. A system left to itself will pass from a less probable to a more probable state and settle into equilibrium when the most probable state is reached, and this will be when the molecular motion reaches the greatest possible disorder. Now, Planck has shown that the entropy of a system, as usually defined, is a function of the probability of the state of the system. As the system changes to a more probable state, the entropy therefore increases. From this point of view, we may therefore consider entropy, in a sense, a property of the body that indicates the extent of the disorder of the molecular motion. It may be noted that the energy of disordered motion is less available, less capable of direction into a required channel, than the energy of ordered motion. Hence, increase of entropy indicates loss of available energy, and our course in basing entropy on the degradation law is completely justified.

The following statements quoted from Professor Klein's book may be suggestive:

1. Growth of entropy is a passage from more to less available energy.
2. Growth of entropy is a passage from a concentrated to a distributed condition of energy.
3. Growth of entropy is from less probable to more probable states.
4. Growth of entropy is a passage to a state more preferred by nature.
5. Growth of entropy is a passage from a somewhat regulated, to a less regulated state. It represents, in a certain sense, Nature's escape from thralldom.
6. Entropy is a universal measure of the "disorder" in the mass-points of a system.
7. Entropy is a universal measure of Nature's preference for the state.
8. Entropy is the universal measure of the spontaneity with which a state acts when it is free to change.
9. Change of entropy constitutes the driving motive in all natural events.

This is a very incomplete and imperfect outline of Professor Klein's important work. I hope, however, it may stimulate a few to read the book.

A SHUTTLE SYSTEM FOR CHICAGO SUBWAYS.

A. S. Robinson, M. W. S. E.

Presented February 8, 1911.

In the hope that this Shuttle System may contain features of sufficient merit to receive consideration at its hands, the writer presents this paper to the Western Society of Engineers with a full appreciation of the magnitude of, and the difficulties to be met in the solution of the problem of subways for the business district of Chicago.

The subject has been under consideration by him since the presentation of his paper to this Society on September 19, 1906. The plan then suggested was open to the objection of centralizing, and therefore tending to congest, rather than distribute the travel in the Loop district.

Mr. Sunny's remarks on Chicago subways, at the annual dinner of the Society in January, 1910, are so parallel with the lines of this plan on which the writer has been working, at every available opportunity since 1906, that he is encouraged to present for your consideration and discussion, this paper, embodying his ideas, the preparation of which has been in the nature of a pleasure rather than a duty.

The belief is also expressed that the subject of the subways should be discussed, not only by the City Council's efficient committee on Local Transportation, but by every engineer who takes an interest in the welfare of the city.

With these ideas in mind, this paper treats only of the characteristic features of this system and its related subjects, since the problems of construction, disposition of public utilities, financing the undertaking, etc., are common to all the plans, and to the plan that will finally be adopted.

The immediate relief from the congestion, and consequent unsatisfactory condition of travel through the business district of Chicago, is evident and needs no comment. With these conditions rapidly growing worse, an early beginning of underground construction, both for passenger transportation and other public utilities, is becoming very urgent.

The primary object of the subways is the rapid movement of the street cars in the business district of Chicago. If the maximum efficiency can be obtained in this direction, accessibility comes next as a determining factor in the rapid handling of the traffic during the rush hours, for the test of the efficiency of any system will come at these periods in the day.

To accomplish the first of these requirements, which would mean correspondingly accelerated rapid transit to all parts of the city, the surface tracks must be removed from the streets and placed in subways having a minimum of curvature, no grade crossings, an absence of steep grades, as many stations as possible having long platforms, and where all cars or trains move in the same direction on their respective tracks. Accessibility will be accomplished by so routing the subways as to give the maximum accommodation to the greatest area. The system should be simple and along direct and natural lines of travel, making it easy of operation and easily understood by everybody. It should have wide, easy stairways in the stations that separate incoming from outgoing passengers, where the act of entering the subway stations, the purchase and deposit of tickets, and the arrival at the point of embarkation can be accomplished with the least check in the flow of traffic along the lines of least resistance, and where the outgoing crowds will find quick and easy exits with the least resistance.

The routing of the subway lines through the business district, to accomplish the least resistance, and the most rapid movement in that area, is of first importance, and must be worked out as a whole before any commencement can be made on the initial construction. This is in order that whatever work may be done on the first lines built, or at any time, may be an integral part of the completed system. It should be done in such a way as to give the maximum car and passenger capacity, and to accommodate all of the surface street-car lines of the present, as well as of the future, from the North, West, and South Sides whose objective is the down-town district. Chicago's problem is that of building a subway that will accommodate all classes of surface rolling stock, singly or *en train,* of the Chicago City Railway, and the Chicago Railways Company.

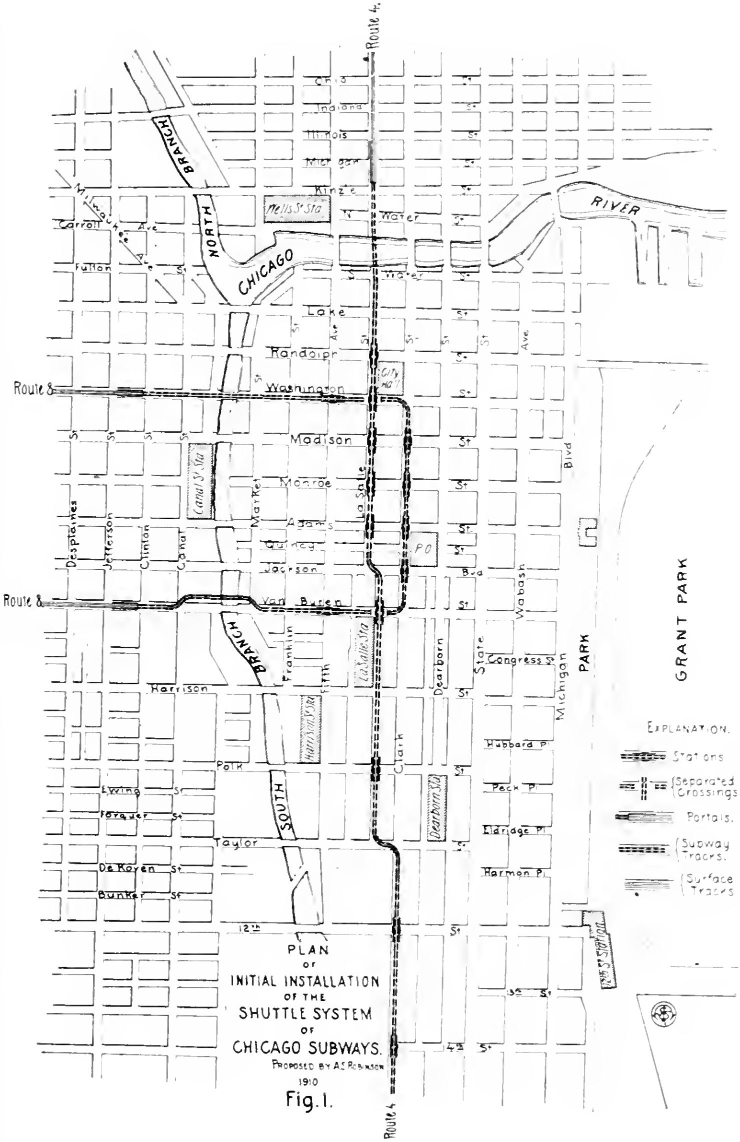
The initial installation of subways as shown in Fig. 1, in the Shuttle System, contemplates the use of the two tunnels under the river at Van Buren and Washington streets, and the tunnel at La Salle street. This would accommodate all of the present street-car traffic approaching the business district from the north, west, and south on La Salle, Washington, Van Buren, and Clark streets, and probably, by reason of increased facilities for rapid transit, one or two other lines that might be diverted near the portals into these two subways.

In Fig. 2 is shown a map of the completed installation of the subways, as contemplated under this system for the purpose of this paper, showing double tracks only, for the sake of clearness, on all of the streets occupied.

Whenever the width of the streets will permit, four tracks should be built; the inside tracks to be connected by cross-overs with their respective main tracks, and used as passing tracks to advance loaded cars around stations at which cars are receiving.

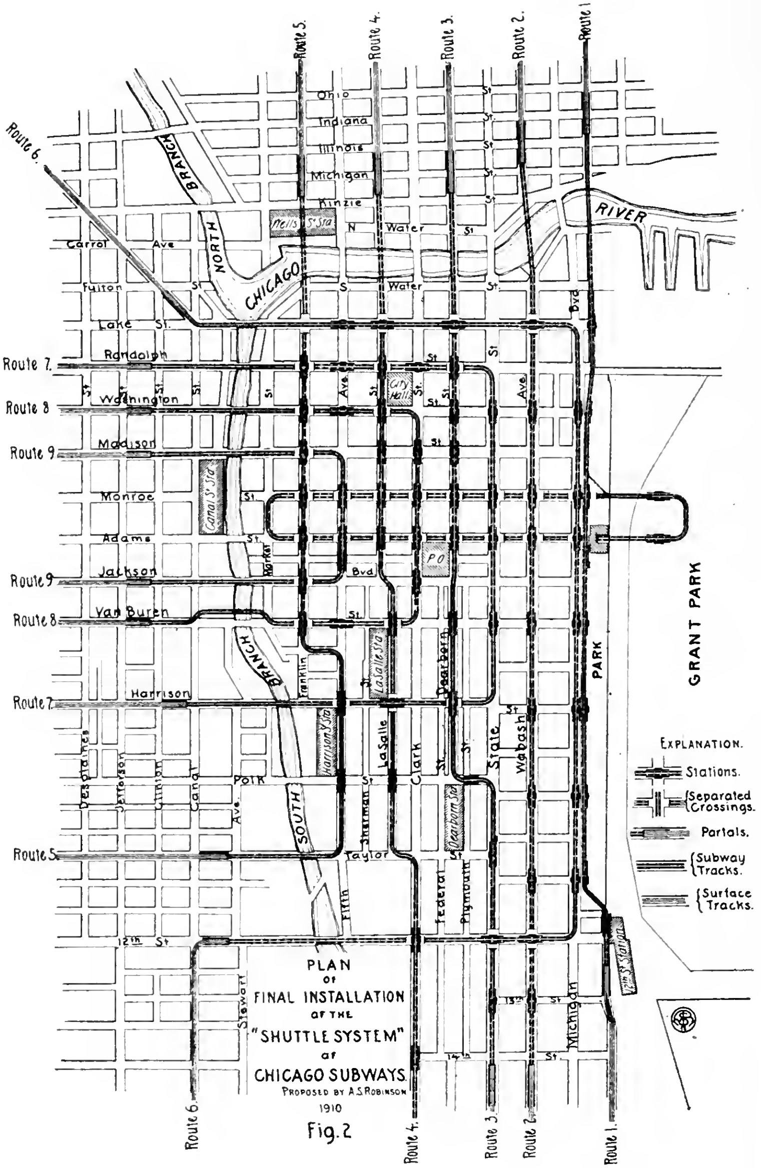
If the width of the street will permit of three tracks only, the middle track should be separately connected at about the dividing line between the north and south bound traffic with its main track and used for the same purpose.

It is not expected that this routing need be followed exactly, but this plan is presented as an illustration of one example under



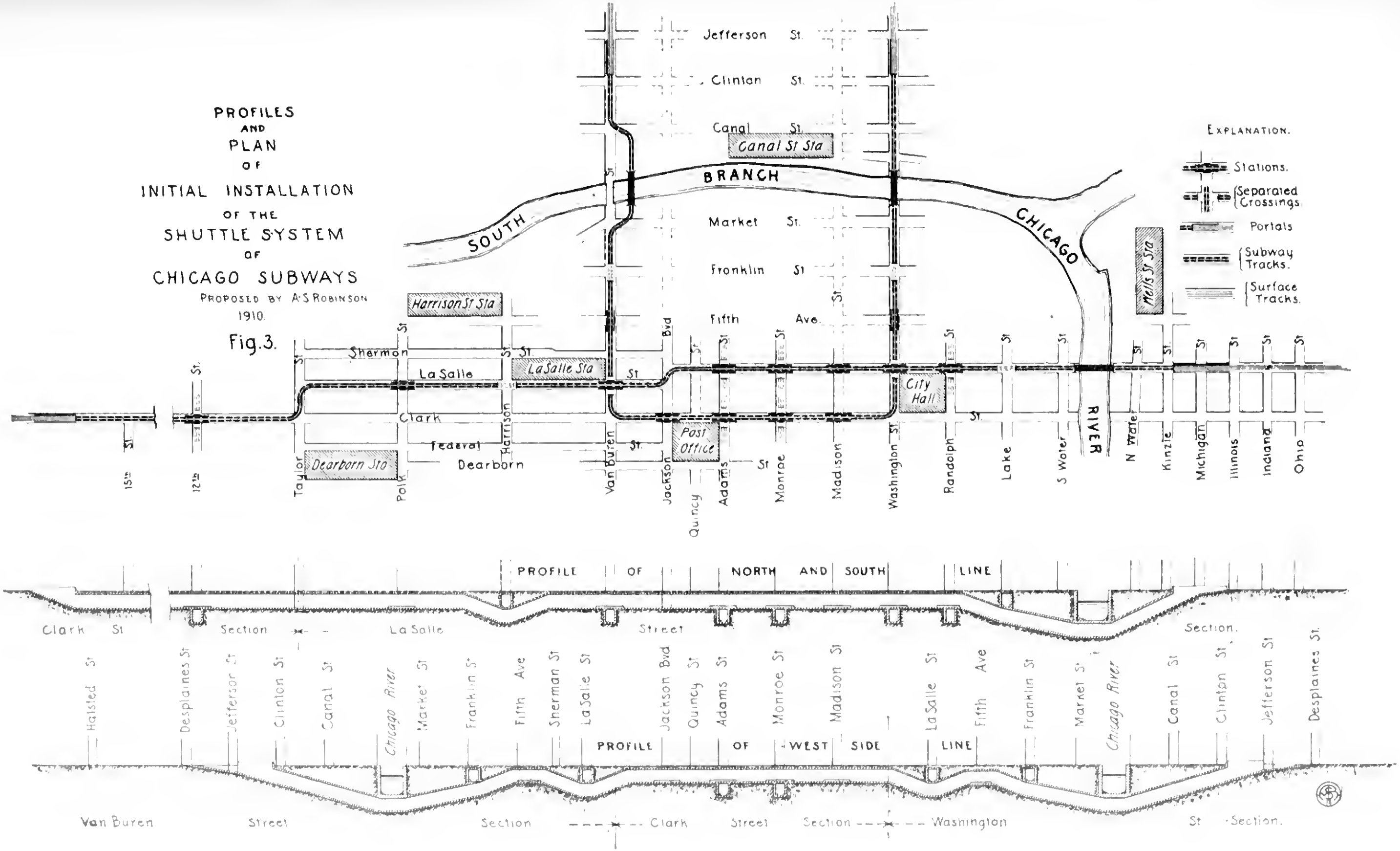
PLAN
OF
INITIAL INSTALLATION
OF THE
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.
PROPOSED BY A.S. ROBINSON
1910

Fig. 1.



PLAN
OF
FINAL INSTALLATION
OF THE
"SHUTTLE SYSTEM"
OF
CHICAGO SUBWAYS.
PROPOSED BY A.S.ROBINSON
1910

Fig. 2



PROFILES
AND
PLAN
OF
INITIAL INSTALLATION
OF THE
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS
PROPOSED BY A. S. ROBINSON
1910.

Fig. 3.

this system, and in order that the initial routing might be determined upon, thus making it an integral part of, and in harmony with, the whole system when completed.

An inspection of this map shows that Chicago would be divided, for transportation purposes, into practically two sections, the north and the south, with the imaginary line of demarcation on Monroe or Adams street. In this way cars would be routed entirely through the business district from one section to the other, either to convenient points in the vicinity of the portals, or to the ends of the lines, where their direction would be reversed for a return trip.

It is intended that the loop line shown on Monroe and Adams streets, if found desirable to build, would act as a transfer only, and would be the only line of the system having stations on the lower level.

In Fig. 3 is shown the typical profiles, as well as the routing, of the initial installation. From an inspection of these profiles, which are also typical in their features of all the lines in the completed plan (Fig. 2), it will be seen that the stations of all of the lines, except the transfer line, will be on the upper level. In order to avoid grade crossings, one of the lines is carried under the other at street intersections, coming again to the upper level as rapidly as possible within the limits of maximum grade, which is determined by the tunnel approaches, thus putting the stations on the West Side lines on the upper level, and the same minimum stairway distance below the street surface as the North and South Side lines.

These are the characteristic features of this system, and the ones the writer desires to emphasize. As no station is contemplated, at these intersections, for the lower line, the existence of this crossing will not be appreciable to passengers on the cars of either.

By introducing separated grade crossings in this manner, and bringing the cross-town lines from the West Side to the upper level. all these passengers are on the same stairway footing as those from the North and South Sides, and no division of the city is handicapped by having to use stations on the lower level for direct communication, because in this way the lower level subway, as such, with its attendant objections, would not be necessary.

All the drawings accompanying this paper are necessarily typical, and are intended to illustrate conditions that are likely to be met in working out this system. The unit lines or routes composing this system have been numbered, for the purpose of this paper, as shown on Fig. 2. Routes Nos. 1, 2 and 3 are each 1.5 miles long, No. 4, 2 miles, No. 5, 1.85 miles, No. 6, 2.85 miles, No. 7, 2.25 miles, No. 8. 1.5 miles, No. 9, 1.05 miles, and the transfer, 2 miles, making a total for the upper level routes of 16 miles, or 18 miles including the transfer subway.

Routes No. 4 and 8 together have been indicated as the initial installation, because the present existence of the river tunnels, which determines the location of these two lines, makes them the logical routes to be built first. This complies with Mr. Arnold's recommendation, in his second report to the City Council, as applied to this system.

The length of the north and south line (Route 4) is 2 miles. The West Side line (Route 8) is 1.5 miles, or a total for the initial installation (Figs. 1 and 3) of 3.5 miles. Of this, approximately 3,600 feet may be changed to river tunnel construction, or at the rate of 1,200 feet for each of the tunnels.

The sewers, water, gas, and steam pipes, and the conduits for all classes of electrical transmission, if carried between the building line and the side walls of the subway, may all be led to their destination in this system by following the lines of the subway. At stations, the sewers would be carried on their respective gradients behind the rear wall in the cross street, and under the stairways. In this way, under the high level system, sewers from any given point in the business district may be discharged into the river. Under a lower level, separate sewerage system, this disposition would be manifestly simpler.

Fig. 4 is a vertical cross-section through an upper level station, and a longitudinal section through a transfer station, illustrating the accommodations to both. An inspection of this and the plan in Fig. 5 will show the simplicity of this arrangement and the ease with which passengers can enter and leave the stations.

In Fig. 5 the pipe galleries for the public utilities are shown between the building line and the side walls of the subway. The different positions back of the station walls in the cross street illustrate possible locations to accommodate different elevations of the conduits.

Figs. 7 and 8 represent a section of a separated grade-crossing, showing one subway, with simple tunnel section crossing under a station on the upper level.

Figs. 9 and 10 show sections through a simple upper-level station where no other line crosses.

Fig. 11 is a typical double track tunnel section between stations, showing the space in a 60 ft. street available for public utilities in the pipe spaces indicated.

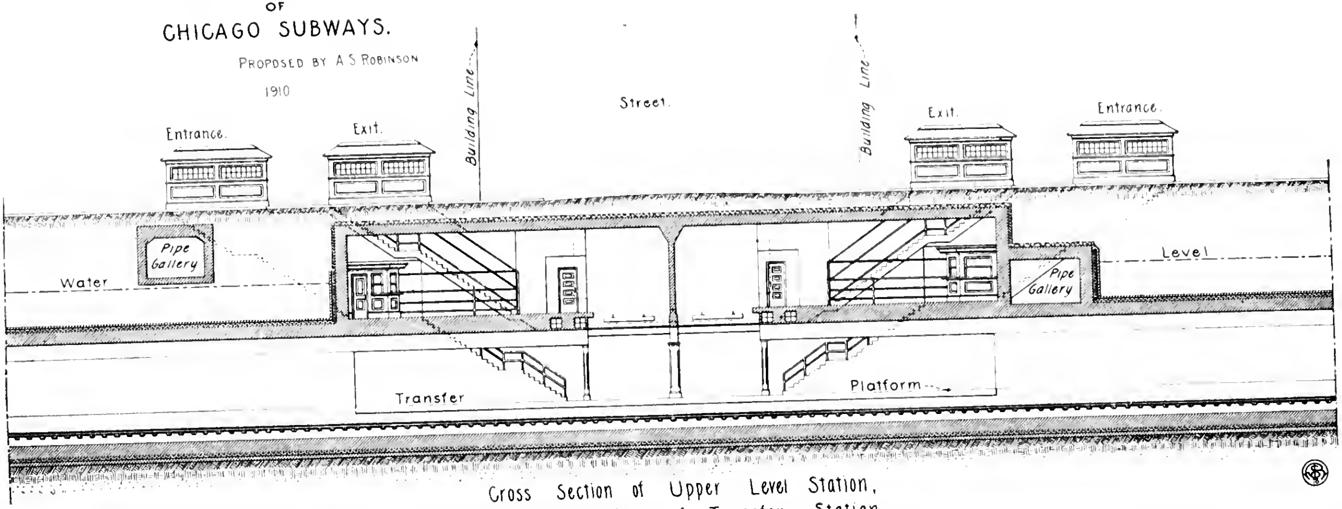
In this system, stations may be located as frequently along the individual lines as the traffic warrants, and the number shown here is 74. The general plan is that in use on the Interborough, and planned in the Tri-borough subways of New York City, where street intersections are about at right angles. The only change that has been made from the original form on the Interborough system is in lengthening the platforms.

The platforms may be connected and made continuous where the traffic demands it, as on lower Broadway, New York. In fact these platforms, by proper railing arrangements, may be

TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.

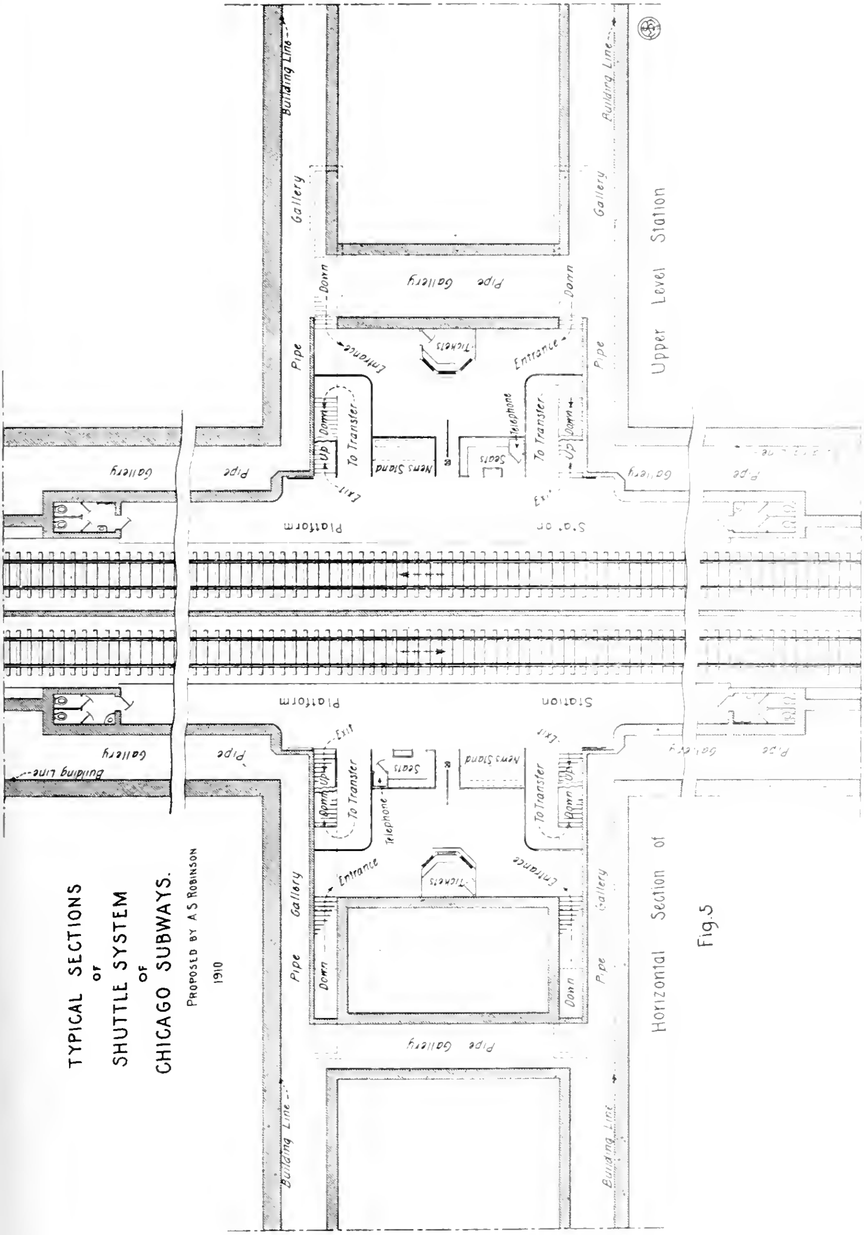
PROPOSED BY A S ROBINSON

1910



Cross Section of Upper Level Station,
Longitudinal Section of Transfer Station.

Fig. 4.



TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.
PROPOSED BY A S ROBINSON
1910

Horizontal Section of Upper Level Station

Fig. 5

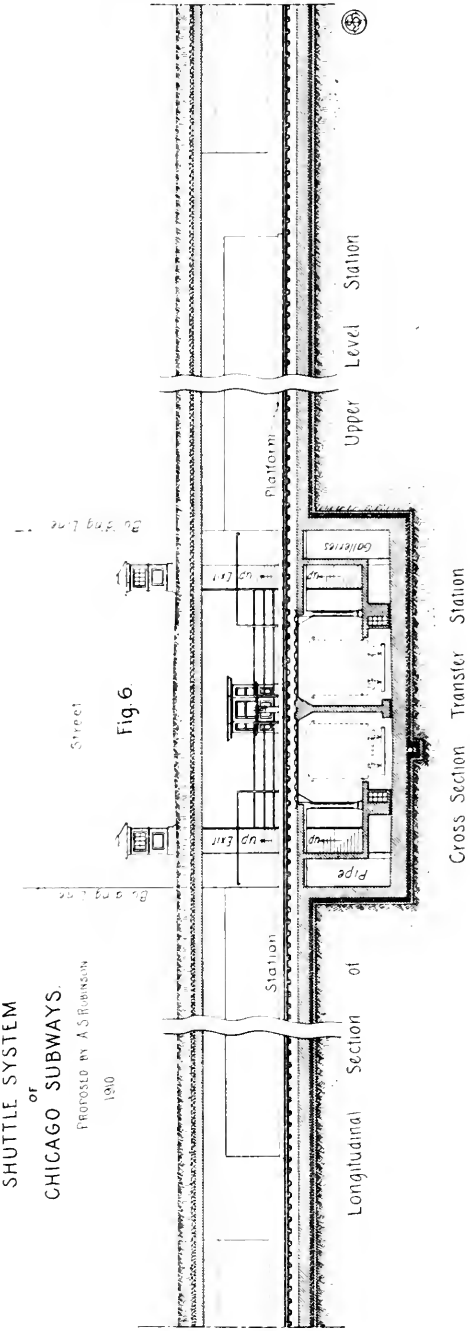
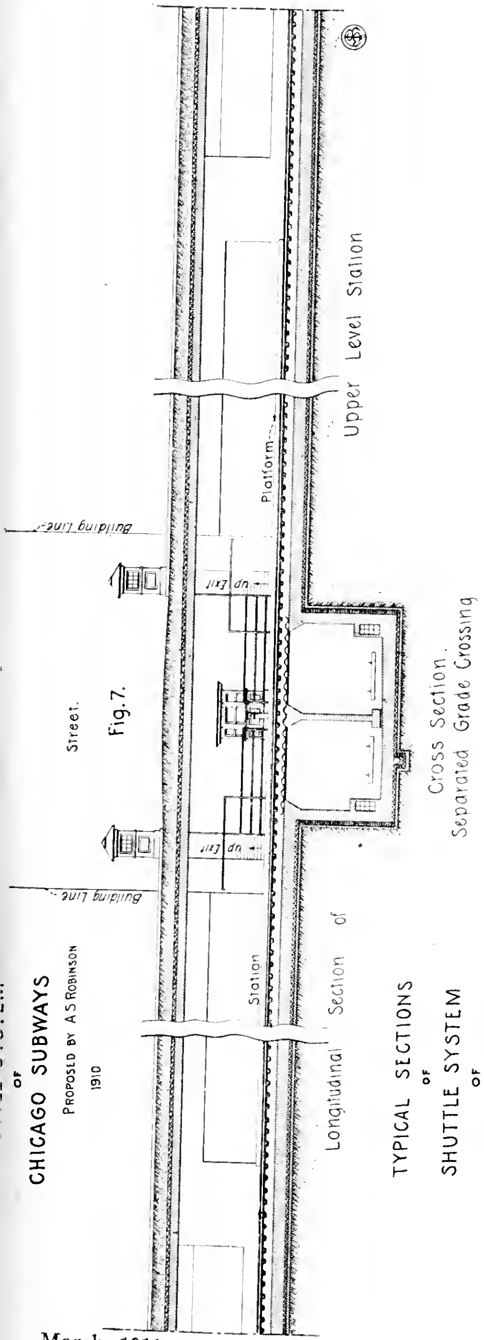
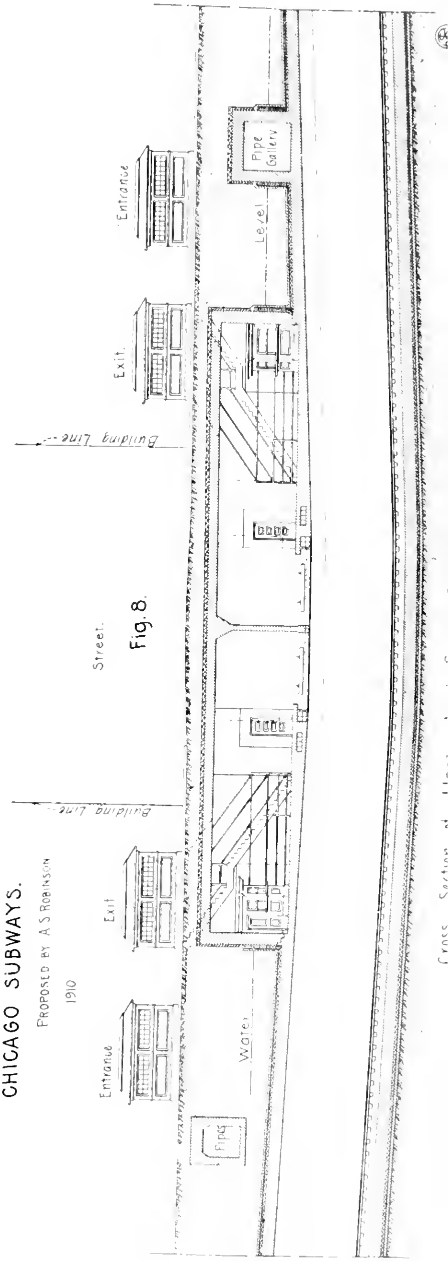


Fig. 6.

TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.
PROPOSED BY A. S. ROBINSON
1910


OF
CHICAGO SUBWAYS
Proposed by A S Robinson
1910
Street.
Fig. 7.
Building Line
Building Line
Up Exit
Up Exit
Platform
Station
Longitudinal Section of
Upper Level Station
Cross Section.
Separated Grade Crossing
TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.
Proposed by A S Robinson
1910


Street.
Fig. 8.
Building Line
Building Line
Entrance
Exit
Exit
Entrance
Pipe Gallery
Level
Water
Pipes

TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.

PROPOSED BY A.S ROBINSON
1910

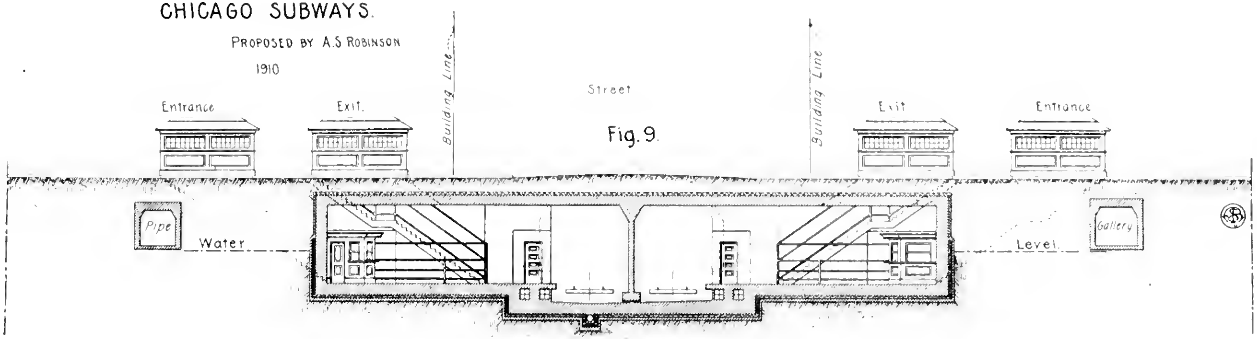


Fig. 9.

Cross Section of Upper Level Station

TYPICAL SECTIONS
OF
SHUTTLE SYSTEM
OF
CHICAGO SUBWAYS.

PROPOSED BY A.S ROBINSON
1910

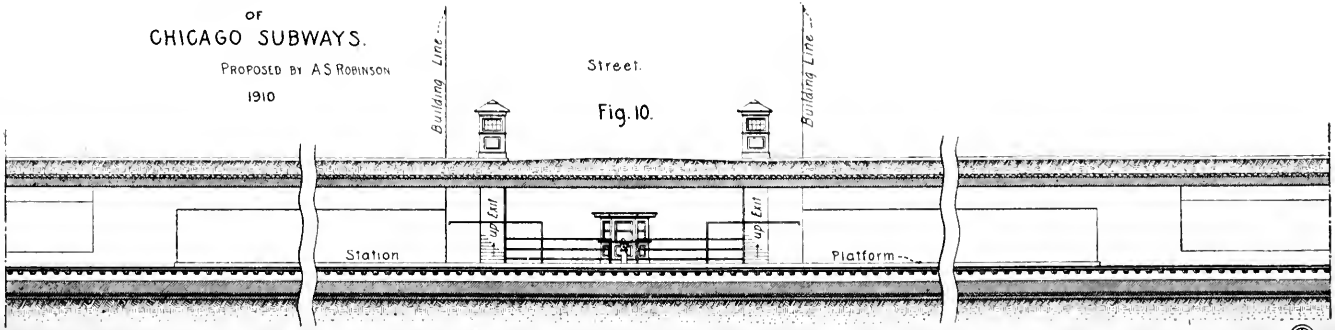


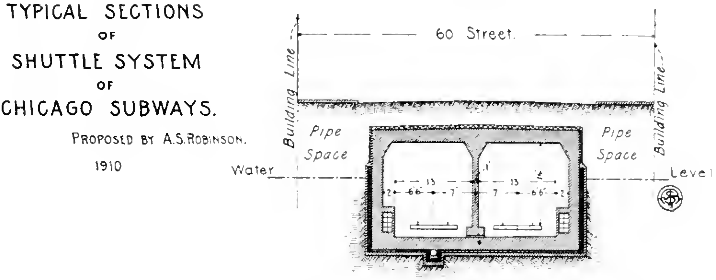
Fig. 10.

Longitudinal Section of Upper Level Station used to meet Mr. Burnham's suggestion for by-passes for pedestrians in the congested streets. When the arrangement of the public utilities can be made to conform, these station platforms may be connected with office buildings, stores, hotels, theaters, and railroad stations, since the latter are all reached.

In the plans of this system it is assumed that the full width of the street will be occupied, or so much of it as is found necessary to properly dispose, not only of the subway, but the public utilities for the present, as well as for the future. The sub-sidewalk space, which belongs to the city and the public, can thus be used for the disposition of water, sewer, gas, steam, electric, and other public-service conduits, affording easy access for inspection and maintenance. This dispositon will save the future disturbance of the paved surfaces of the streets.

The deep excavations will be confined to grade separations at the street intersections and to the transfer line on Monroe and Adams streets. Not including the transfer line, this will be less than 10% of the total length of the excavation; including the transfer line, approximately 17%. The cost of protecting the foundations of abutting property during construction will therefore be the minimum.

Fig. 11.



Typical Cross Section of Double Track Subway.

The location of the portals of the subways will necessarily be on the north and west sides of the river, and as far south on the South Side as expedient. All the street car lines occupying the streets in the immediate vicinity of the portals, and such others as the capacity of the subways would warrant, would be led into them.

In general, the traffic from the overlying streets would be diverted to the subway under it as each route was completed, and as the general direction of travel would thus be maintained, the subway routing would be easily understood by the traveling public.

A characteristic feature of this Shuttle System is that it is a combination of ten short units or independent routes, each complete in itself. Any one or more units may be built at any time as traffic demands, thus affording its proportion of relief immediately upon completion, the ten routes together making a system by which every street in the business district is reached from all parts of the city with the least effort.

If this progressive method of building is followed, the outlay for subway construction would not be burdensome at any one period, and would be coincident with the relief to be obtained.

On the transfer line stations are planned at each intersection with the upper level lines, and one or two in Grant Park.

In Fig. 6 the special equipment of the transfer line is shown having the station platforms at the car floor level. Besides facilitating the movement of passengers, this arrangement saves stairway distance. These cars would be practically open on the platform side and be divided into numerous compartments with partitions to reduce the surging, and increase the comfort of passengers when stopping and standing. A variable speed, moving sidewalk, using for instance Mr. Isham Randolph's system, might be adapted to advantage.

If the lower level construction of this transfer line is not desirable or practicable, a foot way tunnel in the nature of a connecting arcade, can be substituted in either Monroe or Adams streets, affording passengers a simple and effective means of making a transfer.

A connection is planned under Grant Park between the transfer subway and an upper level line for the purpose of handling the transfer cars to and from that line.

After the completion of an additional route or unit line between the North and South Sides, and another to and from the West Side, for instance Nos. 3 and 7, the first installation, lines Nos. 4 and 8 as shown in Fig. 1, might then be used by the elevated roads within a reasonable expenditure for connections with their present structures, since these two subways, in this example of routing, are the most conveniently located. The Northwestern and the South Side could use subway No. 4 and the Lake Street and Metropolitan No. 8, each operating through the business district to the others' terminal, or to convenient junction stations on the others' line. If upon final survey it should be found possible to build four tracks in these two subways, with island platforms, terminating in three tracks for express service, they would be better accommodated than on the present Loop with less track distance in the business district. It is evident that if its traffic could be transferred to the subways, the necessity for the existence of the Loop structure would cease.

The details of loading points on the platforms, headway of cars, through routing, automatic block signals, interchange of traffic, unification of management, in whole or in part, and other matters of operation, are common to all systems or plans, of a comprehensive scope, and must be left to that department.

In the matter of the ventilation of its subways, Chicago will have the benefit of the experience of the other cities, and more favorable conditions. The numerous stations with ample stairway openings will be an assistance, and the dividing wall between the tracks of opposite moving cars, recommended to the Interborough by Mr. Arnold, and adopted in the Fourth avenue extension in Brooklyn, should be built.

For the purposes of this paper the writer has made a preliminary approximate estimate of the cost of construction of Routes No. 4 and 8, the initial installation, as indicated in Figs. 1 and 3. This assumes the portals to be at Michigan and Clinton streets, on the North and West Sides, and between Fifteenth and Sixteenth streets, to avoid the viaduct over the Western Indiana and Santa Fe tracks at Fifteenth street, on the South Side. It includes such portions of the intersecting lines of the completed system as come within the limits of the excavations of the lines under consideration. The unit prices used are in no case less than those of the successful bidders on the Tri-borough subway, and in some items more, although the writer believes the conditions in Chicago do not warrant many of the prices obtained in New York. The track has been estimated as laid and ballasted, as well as the electrical installation, and an allowance has also been made for the tile finish of the walls, and the finishings and furnishings of the stations. This gives a cost of $2,513,000.00 per mile of double track subway equipped, ready to operate, exclusive of the river tunnels.

The Shuttle System, as its name implies, is in no sense one of terminals. Instead, it furnishes a means of through rapid transit in the congested business district of Chicago, the fundamental idea being to provide for the present, as well as for the future, a system sufficiently flexible to develop to its full capacity, the subsurface of the streets.

Discussion

John Ericson, M. W. S. E. (by letter): The question of transportation subways for the city of Chicago has been under consideration for some time, several plans having been proposed by different engineers.

I do not expect that any one of the plans as so far revealed embodies *all* the desirable features in a subway system for this city, but I believe that there are some good features in each one of them, and it is fortunate for Chicago that the Western Society of Engineers has seen fit to take up this very important subject for discussion. The discussion should be thorough and critical.

The writer's views in general, in regard to transportation subways for Chicago, are known through the subway report made by a corps of engineers under his direction in 1909. There are views expressed in that report which are at variance with those expressed publicly by other engineers that have made this subject a study, but the writer stands ready to be convinced with reference to the points on which there is a difference of opinion.

The paper of Mr. Robinson indicates that he contemplates using the LaSalle Street as well as the Washington Street tunnels for his initial subways. It would seem that, with a through-route subway with only a few stations on the proposed initial line in LaSalle Street through the loop district, using the LaSalle Street tunnel for crossing the river, a large number of the North Side cars would be again compelled to cross the river on the bridges, which would be undesirable and a step backward.

The writer is also of the opinion that Mr. Robinson's idea of subway crossings is an improvement on a general low-level system for the east and west lines, as has also been proposed. If such crossings can be avoided, except in streets adjacent to the river, where the lines crossing the river have to be depressed anyway, and yet provide a satisfactory and efficient subway system, this would be preferable.

Such a system the writer believes can be designed without the sacrifice of any essential features.

It seems as if the question of provision for public utilities has been given too little consideration. This problem is perhaps as difficult to solve properly as is the subway problem proper. To merely suggest that the utilities can be put in the alleys or in the sidewalk space is entirely unsatisfactory.

President Chamberlain: Since this paper was written by Mr. Robinson, Mr. Arnold's report has been presented to the City Council, as most of you know, and a copy of that report was placed in my hands this evening by the Secretary. Doubtless there are gentlemen present who are much more familiar with that report than I am, and there may be some who are not at all familiar with it. While the essential feature of Mr. Robinson's plan is, as I regard it, the bringing of the grade of the tunnels at the stations to the upper level, both plans contemplate, as would be natural, the use of the existing tunnels for the initial installations. In the plan presented by Mr. Arnold to the Council last Monday evening, the east and west lines are carried at the lower level and the north and south lines at the upper level. The first installation of east and west lines passes through the Van Buren Street tunnel with a loop on Franklin Street, and the north and south line is substantially the same as that shown by Mr. Robinson.

We have with us this evening Mr. Weston, Assistant Chief Engineer of the Board of Supervising Engineers. I know we shall all be glad to hear from him.

George Weston, M. W. S. E.: I have little to say tonight on the subject of "A Shuttle System for Chicago Subways" in addition to the remarks that I made in the discussion of the paper presented by Mr. Robinson before this Society in 1906.

The principal part of my remarks advocated the through-route system of subways, particularly north and south through the business district, as against the chief feature of Mr. Robinson's original paper wherein he advocated the operation of an "inner circle loop," with which loop all cars entering the business district would connect, and which method of operation would tend to perpetuate the terminal operation of cars in the loop district, with the general effect of retarding the expansion of the central business district of the city, the extension of which is one of the fundamental principles necessary in any subway system for Chicago.

In closing the discussion that followed the reading of Mr. Robinson's paper, he spoke in part as follows: "I rather anticipated that when I said what I had to say it would stir up some discussion, and I think I have exceeded my best wishes." Naturally he defended quite strongly the inner circle system of subway terminals, which formed the subject of his original paper. I note with much pleasure that in the paper Mr. Robinson has presented tonight he advocates a system of through subways north and south through the business district, retaining only the inner circle loop idea, or shuttle system, by a comparatively small low-level loop as an auxiliary, and apparently not considered to be the main feature of the plan. In view of that fact, I take issue with Mr. Robinson on the title he has given to his paper of tonight—"A Shuttle System for Chicago Subways."

My ideas of what should constitute the principal features of a system of subways for the city of Chicago are so well known to most of the members of the Western Society of Engineers, that I will not attempt to restate them further than to quote the conclusions contained in an exhaustive report recently made to the Mayor and the Local Transportation Committee by Mr. Bion J. Arnold, Chief Subway Engineer for the City of Chicago, in which conclusions I heartily concur:

(a) A comprehensive system starting with a nucleus involving a small investment but capable of gradual expansion until the system covers the entire city.
(b) No grade crossings.
(c) High speed straight line operation, with few switches or curves.
(d) Least practicable first cost.
(e) Great flexibility, and always tending to enlarge the business district in three directions.
(f) Ease of access to passengers owing to the shallowness of the high level subways which allows the platforms of the low level subways to be within twenty-eight feet of the surface of the streets.

A. J. Saxe, M. W. S. E.: Will it be necessary to do away entirely with the Illinois tunnel if this subway system is built?

Will it be a matter of waste of all the money that has been put in that tunnel?

President Chamberlain: You are referring to any subway, I presume?

Mr Saxe: Yes.

President Chamberlain: I think Mr. Weston can answer that question better than I can, but my understanding is that the plan submitted in this report contemplates keeping just above the tunnel.

Mr. Saxe: The lower part of the tunnel was 38 ft. below the street level, I think. The tunnel is not shown in the plan.

President Chamberlain: The tunnel is not shown in this plan, but it is in Mr. Arnold's report submitted to the Council. Am I not right, Mr. Weston, in regard to that?

Mr. Weston: Yes. All the plans that have been made contemplate the construction of the low-level subway without material interference with the Illinois tunnel subway. At some locations it may be necessary to modify the top of the tunnel, but it is considered that this can be done very easily.

President Chamberlain: The title of this paper, the Shuttle System, as referred to by Mr. Weston, puzzled me for some time, and I do not know yet whether I have caught Mr. Robinson's idea. But I came to the conclusion, after reading the paper, that the title was derived from the fact that his system of tunnels do not run at a regular grade; that is, there is not a low-grade system and a high-level system. For example, in the plans as submitted by Mr. Arnold, as I stated before, the north and south lines are the high level and the east and west lines the low level. In Mr. Robinson's system he contemplates bringing the tunnels to the high level at the stations and then dropping under the cross tunnels between the stations, similarly to the carrying of a thread by a shuttle, the warp through the woof.

Mr. Weston: In speaking of a shuttle operation of cars in street railroad parlance, it generally refers to a car that runs a short distance and is somewhat auxiliary, we might say, to the main system of operation. I infer that the inner circle loop, for instance, advocated by the author in his first paper, which contemplated such an operation, is what is referred to by the shuttle system. Also in this plan the author shows a loop which he refers to as a tranverse subway, in which the car would be operating as a shuttle car. That is why I questioned the title of the paper.

President Chamberlain: I do not think, myself, the title is very comprehensive, Mr. Weston, but I was trying to reconcile it with the paper.

W. J. Boucher: I am unfortunately unable to discuss Mr. Robinson's paper, to any great extent, but I have had the privilege of seeing Mr. Arnold's report rather intimately, and will mention some things that it contains which have not yet appeared in the newspapers.

The first step in Mr. Arnold's plan is almost identical with that of Mr. Robinson's plan. Mr. Arnold advocates the use of the La Salle Street tunnel in coming down from the North Side, and reaching the South Side through Clark Street. There is an alternate route, on Clark or Plymouth Court as far as Fourteenth Street.

Another line would use the Washington Street tunnel, and via Franklin and Madison Streets reach Michigan Avenue; then south on Michigan Avenue to Jackson Boulevard; west on Jackson Boulevard to Franklin Street, and cross under the river, using the Van Buren Street tunnel. These routes are for surface cars only.

Step 2 of plan 1 contemplates east and west lines through Randolph and Madison Streets, looping on Michigan Avenue, for use of the Oak Park Elevated and other lines on Jackson Boulevard and Harrison Street; also looping on Michigan Avenue for use of the Metropolitan West Side Elevated Ry.

The north and south lines, the Northwestern and the South Side Elevated lines, would be accommodated on a four-track line in State Street, or, if it is desired, two of those tracks could be used for north and south through-routing of surface cars. In all the lines it is hoped that utility galleries will be placed between the tracks and the building lines without material inconvenience with the building foundations. It is doubtful if any interference would be caused by the high-level subways. With the low-level subways the utilities will not be disturbed except at the intersections, which are, of course, station intersections.

No physical connections of tracks for trains are contemplated, but stairways are liberal and escalators to the lower level are also contemplated.

One of the features not brought out in the newspaper accounts is that if it is desired and permitted to widen the sidewalks of State Street 5 ft.—that is, from 20 to 25 ft.—a line of platforms can be so arranged that stairways may come down directly on to the platform and either a northbound or southbound train or car can be reached. If, however, it is decided not to widen the sidewalks, then escalators may go down close to the building line to a lower level subway or passageway, and passengers may cross from one side of the street to the other, and by short stairways could reach either platform.

The matter of ventilation has been quite thoroughly gone into, and it is expected that the subways can be kept at a comfortable temperature and positively ventilated by mechanical means as well as by the piston-like action of trains. Drainage and waterproofing have also been carefully considered.

In regard to Mr. Robinson's estimate, I have made some detailed study of the New York bids, and from my acquaintance with work and costs in that city, I should say that those figures are extravagantly high; that they are not at all applicable to conditions or to contract prices in this vicinity.

President Chamberlain: One thought occurred to me as I noticed the carrying of the grade so as to bring the station to the high level and then dropping it from the high level, for instance, between Franklin and La Salle Streets. It seems to me that the short distance between the under crossing of that tunnel,—crossing on the line of Washington Street, for instance, between La Salle and Fifth Avenue,—would necessitate a very steep grade, and in the general system there would be a great many of these grades. I am not familiar with the exact length of that block, but I think it is in the neighborhood of 330 to 350 ft.; with a 300 ft. platform at Fifth Avenue, and then it being necessary to drop so as to go under the La Salle Street tunnel at Randolph Street, I think there would be gradient close to 10%. In the entire system, as shown on Fig. 2, there would be a great many cases of that kind. That is, these lines would be a series of sharp gradients coming up over a tunnel and then dropping under another tunnel, which, in my mind, would be very objectionable to through traffic, especially to rapid handling of the traffic.

Mr. Weston: In regard to the subject of grades: The plans that have been worked out by Mr. Arnold,—the recent plans,—I believe provide for a maximum of 5% grades on some of the subways where surface cars could be operated. On all high speed subways a maximum of 3% has been adopted. In the original study of the subway system that appeared in Mr. Arnold's report of 1902, the preparation of which I was identified with, when the subject of intersecting subways was considered, it was conceived that after the subways from the west had once dropped to the low level necessary to pass under the river, they then should be retained as low level subways; and after rising to the height permissible, after crossing the river, they were to be operated as subways at a low level. There is no question but what the operation of grades is objectionable on any railroad, and where there are steep grades they are, of course, dangerous and should be avoided, and I think that it is a mistake to change the grade between intersecting subways in order to rise to a higher level. Granting that this might permit of the construction of stations at a higher level, I do not believe that the distance to the platforms of the low-level subways is objectionable.

Herbert H. Evans, M. W. S. E.: It occurs to me, in regard to subway construction, that it is extremely important to provide, as Mr. Weston says, for expansion beyond the present downtown district. I think the time can be very easily foreseen when the present downtown district (the loop district) will be wholly devoted to office buildings, and at that time the greatest surface congestion will be out of the loop district. There will not be much reason for team traffic to go inside of the loop, that is, not nearly so much reason as at present. There is a decided movement west of the river for jobbing and small manufacturing businesses, these being responsible for most of the teaming, and a district of congested streets will grow up over there; for that reason I think it is necessary to provide for initial subway construction which will carry the subway well past such districts. It will defeat the purpose if we build to deliver cars out within the district to become congested within the next couple of decades.

If I understood Mr. Ericson's letter correctly, he states that it would perhaps be a mistake to use the La Salle Street tunnel as a part of the subway, for the reason that the surface cars would be diverted to the bridges. It is my understanding that the surface cars would be put, if possible, through the subway. Should the La Salle Street tunnel be used as it was prior to its reconstruction,—that is, as a mere river crossing for surface cars,—the number of cars which could pass through the tunnel would be limited by the ability to get cars through the downtown section on account of the fouling at surface intersections, and on account of the team traffic that the cars would encounter; in consequence, the maximum capacity of the tunnel would not be available. We could put cars through the tunnel faster than we could get them down through the business district and back again, and if we put the cars wholly under the surface, then we can utilize the tunnel to its full capacity. In addition, the capacity of the tunnel will be somewhat increased by the subway connections, for the reason that the temporary surface connections are at a somewhat heavy grade. Consequently a slower headway can be maintained through the tunnel than when the subway connections are made at a much less grade, and higher running speed and shorter headway can be made possible without undue hazard.

Mr. Boucher: In regard to Mr. Evans' first remark, Mr. Arnold's comprehensive map, which has not been published, I think, in any of the papers, shows routes radiating out from the business district, north, northwest, south and west, and southwest, such that the total single-track mileage is considerably over 400 miles of single-track in the subway, which will, of course, provide the city for a long time to come.

President Chamberlain: One question occurred to me in regard to the cost. I think Mr. Boucher said that the estimates given in Mr. Robinson's paper were exceptionally high. Did I understand you correctly?

Mr. Boucher: I said that the figures submitted by the bidders in New York are exceptionally high.

President Chamberlain: I believe Mr. Robinson states in his paper that his figures are based on New York estimates.

Mr. Boucher: Yes, I think he makes that statement.

President Chamberlain: I notice that in Mr. Arnold's report he gives estimates for the different installations. I have not had time to go over this report carefully, but for the first north and south installation the cost of the two-track subway—4.128 miles of single track, four stations—ready for operation, is $726,710 per mile. That is the north and south installation, from the southern portal of La Salle Street tunnel, via La Salle, Madison, and Clark Streets to Archer Avenue. This would be, for the double-track system which Mr. Robinson contemplates, only about $1,500,000 per mile, instead of $2,500,000 which I think he gives. It would look as though the figures submitted by Mr. Robinson were much higher than Mr. Arnold's estimate.

E. D. Martin, M. W. S. E.: I would like to inquire if anyone can throw any light on what it is proposed to do in the way of existing building foundations, most of which project over the building line into the streets on to public property. I do not understand whether it is going to be necessary to remove the buildings; whether it would be the attitude of the city that the property owners should stand the expense, or whether some means would be devised to overcome that difficulty. In recent operations, lawyers have advised that all foundations be kept inside of the building line. In some buildings with which I have been connected it resulted in a great deal of expense. I know that the owners of the property and people connected with the building industry at that time regarded it as unnecessary.

President Chamberlain: The question, as I understand it, is whether, where foundations encroach on the street, it would be necessary for the property holders to pay the expense of putting those foundations back to the building line.

Mr. Martin: Yes, you are correct.

President Chamberlain: Probably Mr. Weston can answer that question. I presume that he is familiar with the matter.

Mr. Weston: I do not believe that I can, Mr. President. I think the city contends that when it is conducting improvements it can exercise the right of eminent domain and can construct subways or sewers or any other necessary public improvement; also, if the construction of these improvements involve the safety of a building or damage to a building or to its foundations, it is the duty of the property owner to take care of the building and foundation. Whether that contention can be extended or not, I do not know. That is a question for a lawyer to decide. There is no doubt but that, in the construction of the subway in some locations where buildings are on floating foundations, the buildings will require care. I do not believe any one has ever attempted to determine who will be responsible. I think that is one of the questions yet to be decided.

President Chamberlain: As a general proposition, of course, we probably all know that if there was an encroachment on the street it would undoubtedly be the duty of the property holder to take care of it. I do not think any property holder has a right to even build his foundation into the street. We all know that in dealing with the public service corporations the city always takes the ground that the city's rights come first. If a public service corporation has a telephone line or any conduit which is placed in the street and the city finds it necessary to make an improvement in that street, the corporation has to move its conduit, or whatever it may be, at its own expense, absolutely. The city's rights are paramount. I would suppose that the same ruling would obtain in regard to individuals' foundations which are an encroachment on the street. I think the city could order them to set the foundation back to the line.

Another matter that would come up would be the protection of the foundations on account of the possible undermining, and on that question I do not know what would be the decision.

Paul E. Green, M. W. S. E.: Mr. Ericson brought out a point in his paper that I think has not been dwelt on,—I have no doubt Mr. Arnold's report took it into consideration,—and that is the question of the public utilities. I suppose that no one, unless he has been intimately associated at some time with street work, has any idea of the intricate mass of underground work here in the loop district. In some places at present the public utilities occupy the streets solidly from curb to curb, and lower down, of course, are the sewers and the water supply. The streets are so completely congested that it is utterly impossible to build a catch basin and connect it to sewers. We cannot get over them and we cannot get under them and drain. Some of the things that must be taken care of are the telephone company's conduits, the sewers, the present water system, the proposed high pressure water system, probably, unless, as has been suggested, the high pressure water system is attached to the loop structure, the gas, and also the extension of the pneumatic system which is being put in from time to time. The sewers in this loop district, of course, practically all empty into the river, but in the loop district itself the population is estimated as high as one million a day, and the ordinary sanitary sewage, with the restaurants and hotels, would probably be in the neighborhood of fifty million gallons a day. In case of storm or snow, melting snow, and so forth, it might be forty or fifty times that much. It becomes a very simple calculation to figure, therefore, that sewers, to take care of such a quantity of sewage, should be of considerable size, and while I do not recollect what they have been figured at in the various tentative plans, probably a good many sewers are five and six feet in diameter in the downtown district. As Mr. Ericson stated in his letter, the simple statement that the public utilities can be taken care of in the sub-sidewalk space is not enough. The sub-sidewalk space will have about all it can do to take care of water mains and conduits, and so forth, and any report should go deeply into the question of the disposal of the sewage.

H. J. Fixmer, JUN. W. S. E.: It might be suggested, in speaking of the seriousness of the condition downtown, that the City Council has restricted the height of buildings to 200 ft., formerly 260 feet, which might also imply, if this matter is left in the hands of the Aldermen instead of the engineers, that they could solve the problem by reducing it to 50 ft., in which case, of course, subways will not be required.

Emil Gerber, M. W. S. E.: Speaking of the space for the public utilities under the sidewalk, the author says in his paper that a connecting tunnel might be built, but, as I recall it, he does not state definitely that any sidewalk space should be left on the level of the first subway. The question of subway sidewalks has been taken up or discussed more from a newspaper standpoint, possibly, than from an engineering standpoint; and those of us who are downtown and try to take lunch anywhere from twelve to half-past one o'clock realize what sidewalk space means. As far as the foot passageway is concerned, I suppose that is a serious problem, and I should like to hear from someone on that point.

President Chamberlain: The cross-sections that are shown in Mr. Arnold's report, which, if you have not already seen, you doubtless will see a little later (I am referring to Mr. Arnold's report, not to the paper which was presented this evening), do show in some cases spaces for public utilities under the sidewalk; that is, the subway system is extended to the building line. I am inclined to agree with Mr. Green, from what I know of the congested conditions down in the loop, that the space reserved for public utilities will be over-crowded.

In reply to Mr. Gerber's inquiry about foot passageway, if public utilities were put under the sidewalk I do not see, with a four-track system, where they are going to find any space for pedestrians. If anyone here has solved that problem I shall be glad to hear from him. I do not think there is anything of that kind contemplated in this plan that is presented by Mr. Arnold.

Mr. Boucher: Do I understand that a member is of the impression that the sewers will go through the utility galleries?

President Chamberlain: I do not think anyone has that idea.

Mr. Boucher: So far as the utility gallery in a four-track subway is concerned, it will contain only pipes for gas, water, etc., and conduits for wires.

President Chamberlain: I think it is pretty generally understood that there will be a low sewer system, that is, for the sewage. There will probably be a separate system—I think Mr. Arnold mentions that in his report—for the surface drainage.

Mr. Boucher: Yes; and in regard to the sub-sidewalk pedestrian traffic, on certain streets where only two tracks are contemplated.a promenade or gallery is proposed to extend the width of the sidewalk, on which stores and other kinds of buildings may abut and have entrances and show-windows. In Michigan avenue, ultimately it is proposed to have eight tracks extending from somewhere near the west building line of Michigan Avenue over into Grant Park. Then the eight tracks would be spanned at each cross street by a mezzanine concourse, which would give access to all tracks, and in front of the buildings a promenade gallery would be provided, which would connect all these mezzanines and concourses, and that mezzanine could be extended indefinitely west of Michigan Avenue to Wabash Avenue or beyond, as might be desired.

Bion J. Arnold, M. W. S. E. (by letter): This paper is of interest to me as it comes just at the time when I am editing the final proof of a report to the Mayor of the city of Chicago and the Local Transportation Committee, regarding a comprehensive subway system for this city.

I wish I had known of Mr. Robinson's plan earlier, as it may embody ideas of value. I do not agree with it in principle, however, as its tendency seems to perpetuate the present concentrated business district of Chicago by the introduction of a shuttle loop.

I have only had time to glance at the paper hurriedly, but shall read it carefully at the earliest opportunity. I regret that an engagement will prevent my being present at the meeting of March 8th, when Mr. Robinson's paper will be presented, for I should like to discuss it further.

CLOSURE.

The Author: The title of my paper was suggested, as both the President and Mr. Weston inferred, because of a sort of analogy existing between the movement of a shuttle in the weaving of cloth, and the movement of the equipment on the lines of the plan as I am presenting it. I desired a characteristic title, or name, in order to differentiate this system from the many others that have been presented, to the end that it could be referred to in a concise manner.

I concur with Mr. Ericson in his expression of satisfaction that this Society should take up the discussion of the subject; in fact, I feel like going further and saying that it seems as if it is almost a duty, for, if the Western Society of Engineers does not take a keen interest in the matter, it is like an opportunity lost to it.

I confess to a sense of paucity of detail in this plan, which is due to the nature of my occupation during the preparation of the paper, necessitating my absence from Chicago. I regret this handicap, because I have been unable to avail myself of much information bearing on the problem, particularly in the matters of cost and disposal of the city's public utilities. I appreciate the fact that the latter subject is, as Mr. Ericson says, almost as serious an undertaking as the subway itself. The proximity of the sewers to the street surface, necessitated by their out-fall being the Chicago River, makes the problem seriously complicated. A lower level, separate sewerage system, as suggested by the Gordon H. Nott plan, would simplify the matter very materially. It is apparent to everyone who has given this subject any thought, that these two problems must be worked out together, as they are so closely related. The difficulties are so many and varied, surrounding not only the sewer plans, but all the public utilities, that some very radical departures from the present methods of disposal will have to be made. In estimating the cost of the subways, these things, as well as the interference of the floating foundations, must be taken into account, because the construction of the system entails the destruction and reconstruction of almost all of the present installations. This has influenced me in making the estimate about 40% more than the subway cost.

There are two related points in Mr. Arnold's latest plans that I do not understand. The one is the thinness of the roof supporting the street, and the other, the depth of the platforms of the lower tunnels—only 28 ft. Notwithstanding the fact that the public utilities may be disposed of under the sidewalks, and in the alleys, where available, there should be, according to accepted practice, sufficient backfill over the roof of the subways to effectually absorb the shocks of street traffic, the sound of the subway traffic, and also, incidentally, to accommodate such shallow conduits for telephone, telegraph, steam, compressed air, pneumatic tubes, etc., as might properly be carried in that space.

In the plans of the Fourth Avenue (Brooklyn) extension of the Interborough, this depth was not fixed, but left open to be determined by the gradients and by the conditions as found after the street was opened up. Their tentative plan on this point shows about 4 ft. of back-fill, making the base of the rail about 21 ft. below the street surface. In my plan I have estimated the depth of the platforms, for surface-car traffic, to be about 18 ft. The platforms of such of the subways as shall be used by the elevated roads will be about 15 ft. below the surface.

In view of the fact that the platforms in Mr. Arnold's plan of the upper and lower subways are to accommodate surface cars, which should have not much less than 13 ft. clearance above the top of the rail, it looks to me as if he had committed himself to a very difficult undertaking in establishing the lower platforms only 28 ft. below the sidewalks. Where he has planned mezzanine floors that cross tracks to island platforms, this depth will necessarily be increased about 8 ft. more.

It is evident that the escalators of Mr. Arnold's lower level plan will not be necessary in my high-level system. If the State

Street sidewalks can be widened, as proposed, my system will reap a benefit in still more commodious entrances and exits.

I do not believe that the transfer feature, embodied in the loop line under Monroe and Adams Streets, will have the effect of perpetuating the present concentrated business district, as Mr. Arnold, in his letter, seems to think. Furthermore, I do not consider this feature essential to the success of the system, because I anticipate that most passengers will avail themselves of the "cross town" or encircling lines, outside of the subway area, to reach the subway that will deposit them nearest to their destination. As indicated in my paper, a connecting subway for pedestrians, with or without a moving sidewalk, to be used as an arcade, including store fronts, entrances, etc., where possible, might be substituted, as an elaboration, perhaps, of Mr. Burnham's idea, applied to one or both of these streets.

I do not anticipate that there will be any very general introduction of store fronts and showwindows in the subway. In New York there are only a few. The reason is that on account of the nature and number of public utilities, the space between the subway and the building line will be so occupied as to make it impossible, with few exceptions, to have them. Yet, if it is found desirable, certain stations can be connected, and by proper railing arrangements these parts of the subways can be used for by-passes.

Replying to Mr. Saxe's inquiry concerning the interference with the Illinois tunnels, I desire to say that in this system, only the street intersections, where one subway crosses under the other, and the transfer line, if built, will be likely to interfere. Only upon careful survey can this interference be determined, but it is anticipated that no serious obstacle will be presented, and certainly no destruction of their system will follow.

Referring to Mr. Ericson's criticism regarding the capacity of the initial route through the La Salle Street tunnel, Mr. Evans has replied to his objection better than I can. My idea is expressed on the second page of my paper, but the expression is not so elaborate as that of Mr. Evans'. In addition, there are seven stations in my plan as against three, as I take it, in Mr. Arnold's plan, on practically this same routing.

A reference to Fig. 3 will show that the station at Fifth Avenue and Washington Street is not as near the surface as that at Madison and La Salle Streets, for example. An inspection of Fig. 2 will show that only five stations are affected, as this one, by the approaching grades. These grades are planned to be not greater than the effective maximum. This will determine the depth of the platform below the surface, the idea being that these grades are introduced for the purpose of making a station possible at that point. The benefit of this station, even at a little lower depth, I believe will overcome the objection to the grades.

which will also act as retarding and accelerating grades approaching and leaving the station.

When the time comes that the manufacturing plants will be located outside of the business center, removing with them the attendant team traffic, foot travel will overflow the sidewalks during rush hours, as it does in New York on Nassau Street and Broadway, below the City Hall. If the subway stations are numerous and convenient, it will facilitate the dispersion of these crowds more effectually than if the stations are located at greater distances from each other, even if very commodious. An illustration of this is found in a comparison of the conditions at the Brooklyn Bridge station and the stations at Wall and Fulton Streets, New York, during the rush hours.

Only two tracks are shown in each street for the sake of clearness, but it is not my idea to make that number the limit, as a careful reading of the paper will show. Every unit-route of this system should be thoroughly studied in order to give the subway under each street all the trackage that it will accommodate, up to the limit of its capacity.

Since no discussion of Mr. Arnold's latest plan has been invited, I do not feel at liberty to offer any, except as I have already done, in the defense of my system. I feel impelled to make another observation, however, in the same vein. The valid objection to my 1906 plan was the probable centralizing effect of that loop terminal system, yet the latest plan presented to the City Council perpetuates the loop idea, with its attendant objection of excessive curvature, and of centralization of the business district.

The subject of the subways is too extensive to be included within the limits of any paper of this nature, but as the President has said, it "is a timely subject, and one in which all the people of Chicago should be interested."

PROCEEDINGS OF THE SOCIETY

Minutes of the Meetings.

Extra Meeting February 22, 1911.

An extra meeting of the Society (No. 734), being a joint meeting of the Electrical Section with the Chicago Section, A. I. E. E., was held Wednesday evening, February 22.

The meeting was called to order at 8:20 p. m., with Mr. J. G. Wray as chairman, and about seventy-five members and guests in attendance. There was no business before the meeting. The chairman introduced Professor Charles F. Burgess, of Madison, Wis., who addressed the meeting on the "Electrolytic Corrosion of Iron in Concrete." Discussion followed from Messrs. J. G. Wray, Wm. B. Jackson, R. F. Schuchardt, E. N. Pierce, Wm. Seafert, W. H. Finley, C. A. Keller, A. O. Anderson, G. T. Seely, O. E. Strehlow, R. H. Rice, F. F. Fowle, D. A. Abrams, Max W. Zabel, W. O. Hotchkiss, with a closure from the author.

The meeting adjourned about 9:40 p. m.

Regular Meeting March 1, 1911.

A regular meeting of the Society (No. 735) was held Wednesday evening, March 1st.

The meeting was called to order at 8:20 p. m. with President Chamberlain presiding and about thirty-five members and guests present. The minutes of the regular meeting of February 1st were read and approved. The Secretary reported from the Board of Direction that applications for membership had been received from the following:

John C. Gustafson, Chicago, transfer.
John A. R. Daniels, Freeport, Ill.
John R. Baylis, Palestine, Texas.
Harvey W. Rutherford, Chicago.
E. S. Pennebaker, Chicago.
Floyd E. Bates, Chicago.
Walter C. Douglas, New York, N. Y.

Also that the following had been elected into membership:

Albert H. Gregersen, Chicago	Associate Member
T. A. Jordan, Chicago	Junior Member
John E. McNichols, Chicago	Affiliated Member
Harold P. Fisher, Chicago	Junior Member
O. F. Gayton, Chicago	Junior Member
H. B. Kirkpatrick, Chicago	Member
Glenn P. Beach, Jamestown, N. D.	Associate Member
Wm. R. Brown, Chicago	Associate Member
R. S. Spalding, Chicago	Associate Member
A. B. Whitney, Joliet, Ill	Junior Member
A. L. Burridge, Oxford, Wis., transfer from Junior to	Associate Member
Merle J. Trees, Chicago, transfer from Junior to	Associate Member
A. F. L. Heinicke, St. Louis, Mo	Junior Member
Charles W. Morgan, Chicago	Junior Member
Harry H. Stoek, Urbana, Ill	Member
Curtis C. Saner, Chicago, transfer from Junior to	Associate Member

There being no other business before the Society the President introduced Mr. R. S. Blatchley, of the State Geological Survey, who presented his paper on 'Oil Investigations in Illinois," illustrated by some stereopticon views.

Discussion followed from Messrs. F. W. DeWolf, of the Geological Survey, U. S. Grant, of Northwestern University, H. P. Wheeler of St. Louis, A. Bement, and O. P. Chamberlain, with a closure from the author.

Mr. C. R. Dart offered a vote of thanks to the author for his interesting and valuable paper, which was carried unanimously.

The meeting adjourned about 10:25 p. m.

Extra Meeting March 8, 1911.

An extra meeting of the Society (No. 736), being a regular meeting of the Bridge and Structural Section, was held Wednesday evening, March 8.

The meeting was called to order about 8:20 by the chairman, Mr. John Brunner, with about 75 members and guests present.

Mr. Josiah Gibson, M. W. S. E., was introduced, who gave his paper describing the construction of several Cement Stock Houses for the Universal Portland Cement Company. The paper was illustrated by a number of stereopticon views showing some of the details of construction used in these buildings.

Discussion followed from the Chairman, Messrs. Andrews Allen, A. G. Carlson, F. E. Davidson, Paul P. Stewart, Wm. Artingstall, E. D. Martin, A. C. Warren, Ray S. Huey, S. J. Robinson, R. F. Smith, W. T. Curtis, I. F. Stern, and the author.

The meeting adjourned about 10:15 p. m.

Extra Meeting March 15, 1911.

An extra meeting of the Society (No. 737), was held in the Society Rooms, Wednesday evening, March 15.

The meeting was called to order at 8:15 by President Chamberlain with about 50 members and guests present. There being no business to come before the meeting, Dr. W. F. M. Goss, Dean of the College of Engineering of the University of Illinois, was introduced, who read his paper on "The Illinois Engineering Experiment Station in Its Relation to the Public." Lantern slide views of the station and of some of the apparatus contained therein were shown.

Discussion followed from the chairman, Messrs. W. L. Abbott, Albert Scheible, W. E. Symons, Wensel Morava, A. Bement, C. F. Burgess, with a closure from Dr. Goss.

The meeting adjourned at 10:00 p. m.

J. H. WARDEN, Secretary.

BOOK REVIEWS

A POCKET BOOK OF MECHANICAL ENGINEERING. By Charles M. Sames, M. E. Published by the author, Jersey City, N. J., 1911. Leather; 4¼ by 6½ in.; pp. 218; 4th edition; revised and enlarged. Price, $2.00.

This is a handy little book, small enough, in fact, to be a pocket book and easily carried and ready for constant reference to such data as engineers and students may require in their work. The material has been collected from many sources. The work is essentially a compilation and contains little, if anything, that is startling or new, but it is arranged in good shape. Beginning with Mathematics, under which in condensed form is gathered Weights and Measures, Arithmetic, Algebra, Logarithms, Mensuration, and Trigonometry, there follows a page of Chemical Data, succeeded by a chapter on Materials—as properties and tables of weights of various substances, such as metals, woods, stones, rods, bars, paper tubes, bolts, nails, screws, rope, etc. The Strength of Materials, Structures, and Machine Parts, covers some 24 pages. Following this is Energy and the Transmission of Power, which gives rules for proportions of parts of engines, shafting, journals, ball and roller bearings, gearing, belting, and rope transmission; also friction and lubrication.

The next chapter is on Heat and the Steam Engine, with explanations of indicator diagrams, valve diagrams, calculation of fly-wheels, proportions of engine parts, with over six pages on entropy diagrams and their use.

Steam turbines, locomotives, steam boilers and accessory apparatus are also considered in some detail.

The next chapter relates to Hydraulics and Hydraulic Machinery, with information on water wheels and turbines, pumps, etc. In the chapter Shop Data, much valuable information is given. Electrotechnics covers some 30 pages; the information is much condensed, but valuable for reference.

The book is not a treatise on these several subjects, and its use presupposes that the reader has previously acquired some knowledge and comprehension of the subjects but wishes to refresh his memory on some formulae or data for use. For such purpose the book should have considerable value.

Sundry appendices are added, which contain additional information or data to matter in the main part of the book; this information has been added in the later editions to broaden the value and scope of this hand-book.

The book-making has been well done; the paper, though thin and light, is opaque; the typework and engravings are clear and easily read. Altogether, the book possesses many points of value to the mechanical engineer, and is worth the price.

SMOLEY'S TABLES. Parallel Tables of Logarithms and Squares, Angles and Logarithmic Functions corresponding to given bevels, together with a complete set of Five-Decimal Logarithmic-Trigonometric Tables. By Constantine Smoley, Scranton, Pa. Sixth edition, revised and enlarged. New York, The Engineering News Publishing Co., 1911. Leather; flexible bound; 4¾ by 7 in.; pp. 171. Price, $3.50.

This is a new edition of a well known book for the use of engineers, architects, and draughtsmen. An earlier edition was reviewed in the pages of our Journal, the December, 1908, issue, Vol. XIII, p. 807. Some additional matter has been introduced in the latest edition, increasing the value of the book. This includes tables of squares, cubes, second and third roots, and reciprocals of numbers to 1,000; also, areas and circumferences of circles for the same range of numbers. The table of natural trigonometrical functions has been enlarged to intervals of one minute. The paper typography, presswork, and binding are all that could be asked for. The book should be durable and withstand a good deal of handling and use.

LIBRARY NOTES

MISCELLANEOUS GIFTS.

Bion J. Arnold, M. W. S. E.:
- General Statement of Problem and Description of Plans for a Passenger Subway System for the City of Chicago. Cloth.
- Report of the Pittsburg Transportation Problem. Arnold. Leather.

E. E. R. Tratman, M. W. S. E.:
- Test of Jacobs-Shupert Fire-box. By A. T. & S. F. Ry. Co. Man.
- Proceedings 10th Annual Meeting Wisconsin Clay Manufacturers' Association, 1910. Pam.
- Quarterly Journal, University of North Dakota. Pam.
- Telephone Service in America. J. J. Carty. Pam.
- Pennsylvania Railroad Company's Locomotive Testing Plant at Altoona, Pa. Pam.
- Proceedings American Water Works' Association. 1910. Cloth.
- Fabian Society. State Purchase of Railways. Emil Davies. Pam.
- Earth Pressures, Part II. (Theory of Colietent Soils)). French.

Engineering News Book Department:
- Smoley's Tables of Logarithms and Squares. Sixth edition. Leather.

Norman W. Henley Publishing Co.:
- Drop Forging, Die Sinking, and Machine Forming of Steel. Woodworth. Cloth.

Chicago & Northwestern Railway Co.:
Yesterday and Today. A History of the C. & N. W. Ry. System. Paper.
International Association of Navigation Congresses:
Bibliographic Notes and various pamphlets.

EXCHANGES.

American Society for testing Materials:
Proceedings 13th Annual Meeting, July, 1910. Paper.
Lake Superior Mining Institute:
Proceedings 15th Annual Meeting, August, 1910. Paper.
American Mining Congress:
Proceedings 13th Annual Meeting, September, 1910. Paper.
Ohio Bureau of Inspection of Public Offices.
Comparative Statistics, Cities of Ohio, 1908, Pam.
Boston Transit Commission:
16th Annual Report. Cloth.
South Dakota Board of Railroad Commissioners:
21st Annual Report. Pam.
Association of Transportation and Car Accounting Officers:
Proceedings, December. 1910. Pam.
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Journal of the
Western Society of Engineers

VOL. XVI APRIL, 1911 No. 4

LOCOMOTIVE SMOKE IN CHICAGO.

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Presented February 15th, 1911.

Chicago is the greatest railroad center and one of the largest manufacturing centers in the world. Soft coal from Illinois and Indiana is the universal fuel used to carry on this industrial activity, but as this coal is difficult to burn without making smoke, the result has been to defile the atmosphere with great quantities of smoke and dirt. To reduce this condition to a minimum is one of the problems confronting the engineers of Chicago. Although this same situation is found in all of the larger cities of the Middle West, it is Chicago that is leading and must continue to lead in the intelligent fight against the smoke nuisance.

For years it has been an open question as to how much of the total smoke of Chicago is made by railroad locomotives. It is often stated by railroad officials that the railroads make a very small proportion of the total smoke, and that from a standpoint of smoke prevention the electrification of railway terminals is unwarranted. During the last few months the Department of Smoke Inspection of the City of Chicago has made an investigation to determine the proportion of the total smoke made by the railroads, and it is the purpose of this paper to describe this investigation.

A SUMMARY OF CONCLUSIONS.

The results of this study, the details of which are presented in the succeeding pages, may be summarized as follows:

1. Although the locomotives of the city use only 18½% of the total coal, they make 43% of the total smoke and over one-half of the total dirt.

2. The locomotives consume, within the city limits, 5,600 tons of soft coal daily, or about 1,850,000 tons annually.

3. According to the Ringlemann system of judging the density or blackness of smoke, the average density of locomotive smoke in Chicago is 23%.

4. Railroad locomotives make 43% of all the smoke made in Chicago.

5. Because smoke from locomotives carries with it large quantities of sparks and cinders, such smoke is a greater dirt producer than smoke from stationary plants.

6. Although locomotives make 43% of the total smoke, because of the character of the smoke they produce over one-half of the total dirt traceable to smoke.

7. The lowest average density of smoke produced by any one road is about 10%. This figure probably represents as low an average as can be maintained with steam locomotives, using soft coal.

8. If all locomotives in Chicago maintained an average smoke density as low as 10%, the locomotive smoke would still form 29% of the total smoke and probably produce over one-third of the dirt.

9. Locomotives in the neighboring towns outside of Chicago make an average smoke density of about 41%, showing that the anti-smoke campaign in the city has already reduced the smoke nearly one-half.

10. Approximately 10% of all coal fired in a locomotive firebox is discharged from the stack in the form of cinders. Within the city limits of Chicago about 560 tons (14 carloads) of cinders from locomotive smoke-stacks are dropped every day.

11. There are about 2,200 miles of railway track in the city limits. At all times there are about 1,400 different locomotives working in the city, and during a week as many as 3,740 different locomotives are in Chicago.

CLASSES OF SMOKE MAKERS.

In making a study of the different ways by which the total smoke of Chicago is made, the smoke makers of the city have been grouped into seven different classes, as follows:

1. Central District. This class includes all stationary boiler-plants in the district bounded by Chicago avenue, Twenty-second street, Halsted street, and Lake Michigan, and is composed chiefly of office buildings, hotels, wholesale and warehouse buildings, factories, etc.

2. Miscellaneous Power Plants. This class includes all stationary high pressure boiler-plants except those in the central district. In this group are placed factories, mills, manufacturing buildings, electrical power-plants, packing houses, breweries, gas manufacturing plants, pumping stations, school houses, hotels, hospitals, laundries, etc.

3. Flat Buildings. This class includes all low pressure steam-heating plants in flat or apartment buildings, family hotels, etc. No private residences or buildings having three or less flats are included.

4. Domestic Heating. This class includes all private residences, cottages, two and three flat buildings, etc., which use soft coal, principally in stoves.

5. Special Furnaces. This class includes all special furnaces used in various manufacturing processes other than steam boiler furnaces, such as heating and melting furnaces in steel plants, terra cotta plants, malleable iron plants, forge shops, enameling plants, annealing ovens, baking ovens, china kilns, etc.

6. *Railroad Locomotives.* This class includes all steam-railroad locomotives used in the city limits.

7. *Boats.* This class includes all steam vessels used in the city limits, such as tugs, passenger, freight, excursion and canal boats, pile drivers, dredges, etc.

COAL CONSUMPTION.

As smoke is caused chiefly by the incomplete combustion of bituminous coal, the basis of this investigation is a study of the coal consumption of the city. The Smoke Department has gotten together as much information on this subject as possible, and gives as its opinion that there are burned in the city limits of Chicago annually 10,000,000 tons (2,000 lb. each) of bituminous coal. This figure may be taken for the year 1910 and to include semi-bituminous or Pocahontas coal. From 1893 to 1906 a record was kept of all coal shipped into Chicago and all coal shipped away. This record showed that in 1906 the consumption was about 8,000,000 tons. A curve drawn through the points obtained by plotting this record for the thirteen years between 1893 and 1906 shows that a gain of 2,000,000 tons from 1906 to 1910 is consistent and probable. A check on this total figure of 10,000,000 tons has been obtained by accounting for its use amongst the different consumers of soft coal.

1. *Central District.* This class is estimated to use 1,500,000 tons of soft coal annually. This figure has been obtained by making a careful census of the boilers in this territory and by considering figures obtained from coal dealers. In this district it is estimated that 1,125,000 tons of Illinois and Indiana coal are used and about 375,000 tons of semi-bituminous coal. This semi-bituminous coal is used in the low pressure plants.

2 *Miscellaneous Power Plants.* The coal used by the plants in this class has been obtained by making the following computation:

The records of the Boiler Department and Smoke Department show that there are about 7,000 high pressure boilers in the city and that the average rated boiler horsepower is about 143. A study of the load conditions in hundreds of plants shows that the average load is about 75% of the installed boiler capacity. With these figures the following computation is made:

Number of high pressure boilers in city..................	7,000
Average rated horsepower per boiler....................	143
Total capacity in horsepower of high pressure boilers....	1,000,000
Average load, percent of rating........................	75%
Number of days per year average plant in operation......	300

Number of hours per day average plant in operation......	10
Average pounds of coal used per boiler horsepower per hour	5

Then it follows that the

Total tons of coal used per year in all stationary high pressure boiler plants is...........................	5,625,000

According to the classification of plants, this 5,625,000 tons is the annual coal consumption of Class 2 plus the high pressure plants of Class 1. The high pressure plants in Class 1 have been estimated to use 1,125,000 tons annually, which leaves 4,500,000 tons of coal as the annual consumption of the miscellaneous power plants.

3. Flat Buildings. These plants are estimated to use 750,000 tons of coal per year, most of which is Pocahontas coal. This figure has been obtained by getting at the number of such buildings in Chicago and estimating the average coal consumption per building. There are probably from 1,000,000 to 1,200,000 tons of semi-bituminous coal used in Chicago annually.

4. Domestic Heating. The coal used for domestic heating is very difficult to estimate. It has been decided that 650,000 tons of soft coal annually for this class of plants is as close a figure as is obtainable. This has been arrived at by getting figures from coal dealers and by estimating the number of such consumers.

5. Special Furnaces. The plants in this class are estimated to burn 600,000 tons of coal per year. This is based on figures obtained from a number of the largest consumers.

6. Railroad Locomotives. The coal used by the railroad locomotives has been accurately estimated. The Smoke Department wrote to all the railroad companies and asked for estimates of coal burned by locomotives in the city limits. The returns show a total of 5,601 tons. This is the average for week days. Assuming that the Sunday consumption is one-third of the week day consumption, and that the other holidays in the year do not affect the average, it follows that the annual coal consumption of steam locomotives in the city limits is 1,850,000 tons.

7. Boats. This class is estimated to use 150,000 tons per year. This figure has been obtained by getting estimates from most of the companies operating vessels in the rivers, with their figures as a basis, making up the total estimate.

The division of the 10,000,000 tons is therefore as follows:

CLASS.	CONSUMER.	ANNUAL CONSUMPTION.	PERCENT.
1.	Central district	1,500,000	15.0
2.	Miscellaneous power plants	4,500,000	45.0
3.	Flats	750,000	7.5
4.	Domestic	650,000	6.5
5.	Special furnaces	600,000	6.0

6.	Railroads	1,850,000	18.5
7.	Boats	150,000	1.5
		10,000,000	100.0

DENSITY OF SMOKE.

Knowing the coal consumption of these different classes of plants, it requires a knowledge of the average density of smoke made by each class to arrive at the percentage of the total smoke made by each. For this purpose the department has used the Ringlemann method of estimating the relative blackness or density of smoke. This system was invented by Prof. Ringlemann, of Paris, and is in general use throughout the world. The U. S. Geological Survey has adopted it as a standard. The Ringlemann method of judging smoke is clearly explained in the transactions of the American Society of Mechanical Engineers, Volume XXI, December, 1899.

> "In making observations of the smoke proceeding from a chimney four cards ruled like those in the cut, together with a card printed in solid black and another left entirely white, are placed in a horizontal row and hung at a point about 50 feet from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, which are numbered from 0 to 5, determines which card most nearly corresponds with the color of the smoke, and makes a record accordingly, noting the time. Observations should be made continuously during any one minute, and the estimated average density during that minute recorded, and so on, records being made once every minute. The average of all the records made during a boiler test is taken as the average figure for the smoke density during the test. * * * A rule by which the cards may be reproduced is given by Prof. Ringlemann as follows:
>
> "Card 0—All white.
>
> "Card 1—Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.
>
> "Card 2—Lines 2.3 mm. thick, spaces 7.7 mm. square.
>
> "Card 3—Lines 3.7 mm. thick, spaces 6.3 mm. square.
>
> "Card 4—Lines 5.5 mm. thick, spaces 4.5 mm. square.
>
> "Card 5—All black."

It will be noted that the width of the lines and the area of the spaces are so arranged that the black covers respectively 0, 20, 40, 60, 80, and 100 percent of the white surface of the card. This is graded for convenience into Nos. 1, 2, 3, 4 and 5. By this means, for example, smoke proceeding from the stack which corresponds to card No. 3 is No. 3 smoke, or 60 percent black. In making use of the Ringlemann chart the Smoke Department has figured the results on a percentage basis. The formulæ for computing the percentage of density is:

$$\left.\begin{matrix}\text{Percentage}\\ \text{of}\\ \text{Density}\end{matrix}\right\} = \frac{\text{Smoke Units} \times 0.20}{\text{Stack Minutes.}}$$

Percentage of Density of smoke is the percentage of light that is prevented from passing through it. For instance, No. 1 must prevent 20% of light from passing through it, and, on the other hand, must allow 80% of light to pass through it; No. 4 prevents 80% and passes 20% light; No. 5 is opaque and prevents all light from passing through.

A Smoke Unit corresponds to one minute of No. 1 smoke or its equivalent. For instance, one minute of No. 2 smoke is equivalent to 2 smoke units; two minutes of No. 3 smoke to 6 smoke units; four minutes of No. 1 smoke to 4 smoke units, etc.

A Stack Minute corresponds to watching one smoke stack for one minute. In any set of observations, the stack minutes are obtained by multiplying the number of stacks under observation by the number of minutes during which the observation continues.

Using this method of computing the percentage of density, the Smoke Department has arrived at the following results:

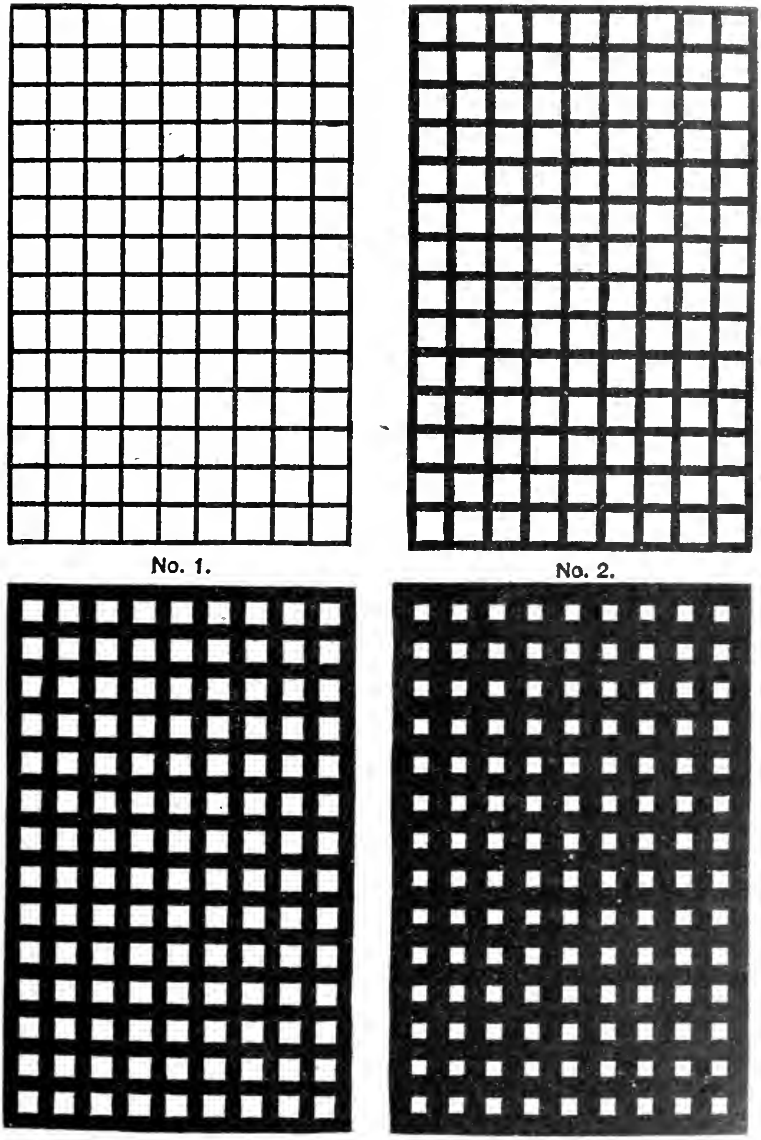
SMOKE DENSITY BY RINGLEMANN CHART METHOD.

CLASS.	CONSUMER.	PERCENTAGE OF DENSITY.
1.	Central district	3.75
2.	Miscellaneous power plants	6.5
3.	Flats	3.0
4.	Domestic	3.0
5.	Special furnaces	20.0
6.	Railroads	22.3
7.	Boats	25.0

To illustrate in detail how these figures were obtained for the stationary plants, the observations made in one block in the downtown district are given in the Appendix (see Table 1).

Similarly, to illustrate how the figures were obtained on the railroads, the observations made during one day are given in the Appendix (see Table 2).

An important part of this investigation of the density of smoke in Chicago has been a study of the smoke made by railroad locomotives. During October and November, 1910, a special observer spent his entire time on the rights of way of the railroads in the city limits. During these two months he made over 11,000 sepa-



No. 1.

No. 2.

No. 3.

No. 4

FIG. 1 —THE RINGLEMANN SCHEME FOR GRADING THE DENSITY OF SMOKE.

rate observations and watched the locomotives of thirty different railroad companies. The observer was assigned each day to a certain point on the right of way of some road, often at a junction of two or more roads, his instructions being to watch every locomotive coming within his sight, and to record in his memorandum book the number of minutes during which he watched the engine and his estimate of the density of the smoke in accordance with the Ringelmann charts. It is probably unnecessary to say that this work was done with absolute impartiality and that no effort was made to watch the engines of one road more than another. Table No. 3 in the Appendix shows where the observer worked during these two months and also shows the average percentage of smoke density at each of these locations. These figures include all the observations made at these points, whether the engines belonged to the company on whose right of way the observer stood or not. This list shows that the dirtiest place in Chicago was at Fifty-fifth street and the C. & W. I. R. R. tracks. This point is also at the south end of the Erie Railroad yards. The average density obtained on this day, the 20th of October, was 45.4%. Similarly, this list shows that the cleanest place was at the Illinois Central R. R. tracks and Van Buren street, where the average density was 10.5% on October 10th.

In the Appendix, Table No. 4 shows the list of all the railroads whose locomotives were observed during this investigation. They are arranged according to the average density of smoke, the road having the lowest average being first on the list. Locomotives of thirty different roads were observed, but in four cases less than fifty observations were made; therefore these are not listed with the others because it is felt that not enough observations were made to arrive at a proper average. This list shows the locomotives of the Wisconsin Central Railway (leased by the Minneapolis, St. Paul & Sault Ste. Marie) as occupying first place with an average density of smoke of 10.76%. The Chicago Junction Railway occupies the lowest position in the list with an average of nearly 42%. The average percentage of locomotive smoke density in the two months' investigation is 22.3%.

DIVISION OF TOTAL SMOKE.

Knowing the division of the total coal burned in the city amongst the seven classes of consumers, and knowing the average density of smoke made by each class, it is an easy matter to compute the division of the total smoke amongst the seven classes.

As far as is known, this is the first attempt ever made to subdivide the total smoke of a city amongst the various classes of plants responsible for its production. The work has been done carefully

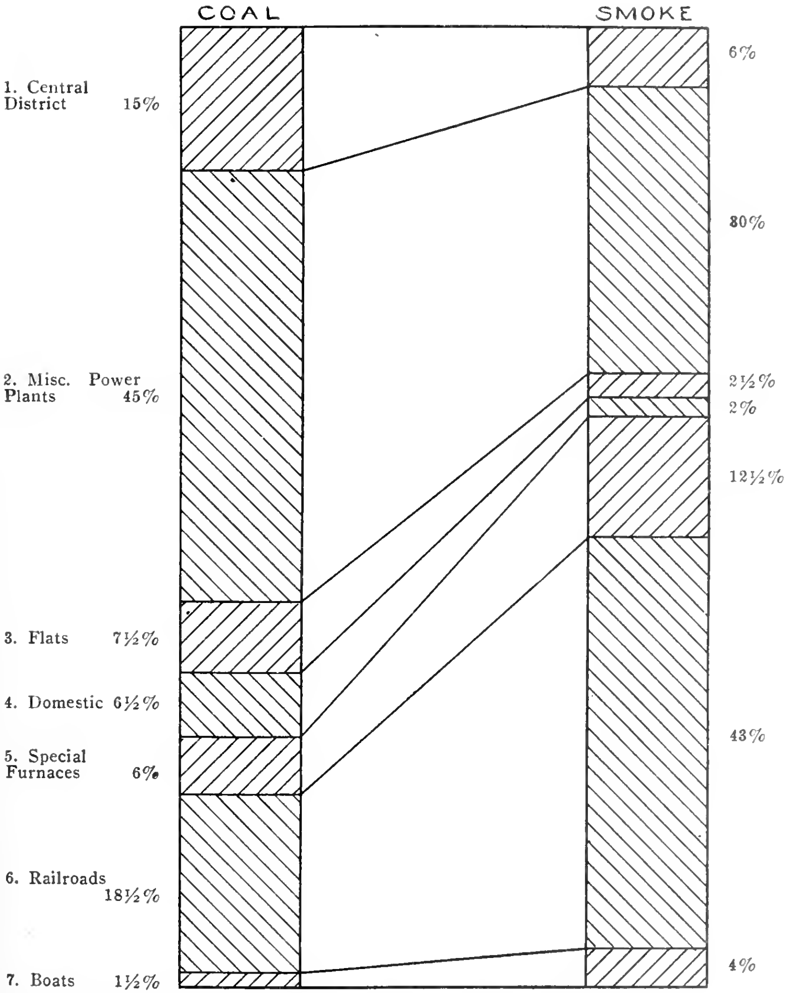


Fig. 2. Diagram showing percentages of total coal and total smoke in Chicago.

and accurately and it is felt that the results obtained are very nearly correct.

		Annual Coal Consumption			SMOKE	
					Percent. of Total Smoke	
Class	Consumer	Tons	Per Cent	Percentage of Density	As Figured	Round Numbers
1	Central District	1,500,000	15.	3.75	5.85	6
2	Misc. Power Plants	4,500,000	45.	6.5	30.45	30
3	Flats	750,000	7.5	3.0	2.34	2½
4	Domestic	650,000	6.5	3.0	2.06	2
5	Special Furnaces	600,000	6.	20.0	12.5	12½
6	Railroads	1,850,000	18.5	22.3	42.9	43
7	Boats	150,000	1.5	25.0	3.9	4
		Total—10,000,000	100.	Avg. 9.6	100.0	100.00

OUT OF TOWN OBSERVATIONS.

During the month of December, 1910, the same observer who had worked in Chicago on the investigation of railroad smoke was sent to eight different towns outside the city limits to make similar observations. Table V in the Appendix shows the results obtained. In this table the railroads are listed according to the density of smoke—the one averaging lowest being first. In these eight towns the density of smoke averaged 41%. This is probably a fair figure for the performance of a locomotive using Illinois or Indiana coal with no particular attention paid to preventing smoke. Table VI in the Appendix gives these results listed according to the towns visited. Streator, Illinois, had the smokiest locomotives, 361 observations averaging 51% smoke density. This indicates the results of the anti-smoke campaign in Chicago. It shows that outside of the city, where no effort is made to prevent it, the smoke is nearly twice as dense as in Chicago. This is true of the stationary plants as well as the railroads. If the citizens of Chicago will compare their city with all other cities in the middle West they will find that, plant for plant, locomotive for locomotive, chimney for chimney, Chicago is the cleanest of all.

CHARACTER OF LOCOMOTIVE SMOKE.

Locomotive smoke carries with it quantities of sparks and cinders, while in stationary plants relatively little of such material is thrown out. This is because of inherent features in the design that are unavoidable. On a locomotive there is so little room available that the grate surface of the boiler is necessarily small and there is consequently required a powerful draft for burning enough coal to do the required work. This draft is obtained by discharging the exhaust steam from the engine cylinders up the stack. Because of this strong draft there is drawn out of the fire box with the smoke great quantities of fine coal and ash, which in turn are discharged from the stack in the form of cinders. It is a recognized fact amongst railway men that from 8 to 18% of all bituminous coal put into locomotive fire boxes escapes from the stack in this manner. In Chicago about 5,600 tons of coal are burned in locomotives each day. Assuming that 10% of the coal leaves the stack in the form of cinders, it means that 560 tons of cinders are thrown into the air and dropped on the city of Chicago every day. This is equal to about 14 carloads. On the other hand, in stationary plants where there is plenty of room for a larger grate surface and where the coal is burned with a lower draft and with tall chimneys, but few cinders are carried out with the smoke. Therefore the smoke from locomotives on account of carrying with it sparks and cinders is far more objectionable than the smoke from stationary plants, and as it is discharged into the atmosphere at no great distance from the ground and is trailed over long courses, it is safe to say that from the standpoint of a nuisance the steam locomotive is the worst offender of all. The investigation already described shows that the locomotives of Chicago make about 43% of the total smoke. Considering its character, the conclusion seems warranted that steam locomotives produce over one-half of the dirt traceable to smoke.

POSSIBILITIES OF LOCOMOTIVE SMOKE PREVENTION.

In the Appendix, Table IV shows that the lowest percentage of smoke density made by the locomotives of any railroad was 10.7%. Probably 10% is as low an average as can be maintained with steam locomotives using soft coal. Therefore the very best condition that can be hoped for in Chicago is to have all locomotives average 10% density, which would mean that the locomotive smoke would still be 29% of the total, and probably be responsible for over one-third of the dirt. The modern steam locomotive is such a highly developed machine that it is extremely unlikely that any change will ever be made in its construction which will produce better results than this. A further reduction of the smoke made by locomotives can only be brought about by change of fuel. The possible fuels besides the local soft coals are: 1st, semi-bituminous coal; 2nd, anthracite coal; 3rd, coke, and 4th, oil. A considerable amount of semi-bituminous or Pocahontas coal is now being burned by some of the railroads in Chicago, and although it makes less smoke than Illinois coal under the same conditions, its use by no means guarantees the entire elimination of smoke. Probably the universal use of semi-bituminous coal would not succeed in reducing the average density of smoke below a point that is considered possible with Illinois coal. The general use of anthracite coal or of coke for locomotives would eliminate smoke, but the other nuisances due to steam locomotives would not be diminished. If coke were used there would be an increase in the quantity of sparks and cinders discharged from the stacks. In either case the volume of furnace gases and their effect in vitiating the atmosphere would not be reduced. Fuel oil makes smoke unless carefully handled, and the smoke that is made is more objectionable than the smoke from soft coal. It is probable that if all locomotives in the city burned oil, the smoke and gases would form more of a nuisance than the soft coal smoke of to-day. The general use of any specially selected fuel would greatly increase the cost of fuel to the railroads, and the practical difficulties involved would make it a very difficult thing to bring about. The locomotive fireboxes would have to be changed if coke or hard coal were used. In order to ensure that all locomotives operating in the city limits used the same fuel, all the engines on an entire division would have to be thus equipped, which of course would greatly increase the cost of operation.

ELECTRIFICATION.

The study that has been made along these lines indicates clearly that electrification offers the only final and satisfactory solution of the locomotive smoke problem. The use of special fuel for preventing smoke on steam locomotives is only a makeshift and will not satisfy the public.

DATA ON RAILROAD TRACKS, LOCOMOTIVES, AND COAL.

During the summer of 1910 the Smoke Department wrote to all the railroads operating in Chicago, asking for certain information relative to the number of locomotives used in the city limits and the tons of coal used per day. The results are shown in Table VII of the Appendix.

TABLE I.

SPECIAL RINGLEMANN OBSERVATIONS.

Date, November 15, 1910. *Observer,* D. J. Sullivan.

Block. Randolph, Washington, Dearborn & Clark Streets.

Hour, 8:45 a. m. to 10:45 a. m.

BUILDING.	NUMBER OF STACKS.	MINUTES OF SMOKE 0	1	2	3	4	5
Rawson	1	110	8	2	0	0	0
King Joy Lo	1	120	0	0	0	0	0
Douglas	1	120	0	0	0	0	0
Quinlin	2	240	0	0	0	0	0
Superior	1	120	0	0	0	0	0
Kedzie	1	113	6	1	0	0	0
Grand Opera House	1	120	0	0	0	0	0
Reaper Block	1	115	4	1	0	0	0
U. S. Express	2	218	12	3	2	5	0
Cole	1	103	13	4	0	0	0
Kerfoot	1	110	3	7	0	0	0
Henrici	1	112	6	2	0	0	0
Total	14	1,601	52	20	2	5	0

1601 minutes of No. 0 smoke = 0 smoke units
52 minutes of No. 1 smoke = 52 smoke units
20 minutes of No. 2 smoke = 40 smoke units
2 minutes of No. 3 smoke = 6 smoke units
5 minutes of No. 4 smoke = 20 smoke units
0 minutes of No. 5 smoke = 0 smoke units

Total = 118

$$\text{Stack minutes} = 14 \times 120 = 1680.$$

$$\text{Percentage of density} = \frac{118 \times 0.20}{1680} = 1.4\%$$

TABLE II.

Special Ringlemann Observations.

LOCOMOTIVES.

Date, October 13, 1910. *Observer,* C. J. Kingsley.
Location, Chicago & Northwestern and Pennsylvania Rys. at Madison street.

Hour, 8:30 a. m. to 4:59 p. m.

RAILROAD.	NUMBER OF OBSERVATIONS.	STACK MINUTES.	SMOKE UNITS.	PERCENTAGE OF DENSITY.
C. B. & Q. R. R.	8	21	13	12.3
C. T. T. R. R.	1	3	2	13.3
C. M. & St. P. Ry.	30	115	98	16.1
B. & O. R. R.	2	3	3	20.0
C. & N. W. Ry.	97	286	342	23.9
Pennsylvania R. R.	25	89	113	25.4
C. & A. R. R.	1	3	12	80.0
Total	164	520	583	22.4

These figures show the results for the entire day's observations. The detail observations made between 2 and 3 o'clock were as follows:

	TIME		DENSITY	SMOKE
LOCOMOTIVE.	BEGAN.	MINS.	OF SMOKE.	UNITS.
C. & N. W. Ry., No. 1138	1:02	3	2	6
“ 437	1:05	1	1	1
“ 1109	1:07	3	3	9
C. M. & St. P. Ry.	1:09	1	4	4
“ 395	1:10	4	2	8
“	1:10	3	0	0

C. & N. W. Ry.,	1149....1:17	2	1	2
C. B. & Q. R. R.	3145....1:18	1	3	3
“	3145....1:19	1	0	0
“	3145....1:20	5	1	5
C. & N. W. Ry.,	1434....1:21	2	1	2
C. B. & Q. R. R.,	3145....1:25	3	1	3
“	3145....1:28	7	0	0
C. M. & St. P. Ry.,	486....1:37	1	3	3
C. B. & Q. R. R.,	3145....1:35	2	0	0
“	3145....1:37	1	1	1
C. M. & St. P. Ry.,	........1:37	2	2	4
“	1164....1:52	4	0	0
C. & N. W. Ry.,	1127....1:55	6	4	24
C. M. & St. P. Ry.,	1164....1:57	5	3	15
“	1164....2:05	2	0	0
C. & N. W. Ry.,	1489....2:11	5	1	5
“	........2:12	1	1	1
“	579....2:13	2	0	0
“	1489....2:16	3	1	3
“	1704....2:16	7	0	0
“	318....2:17	5	0	0
“	1230....2:18	2	4	8
“	1489....2:19	5	2	10
“	1230....2:20	3	1	3
“	1489....2:25	10	0	0
“	1704....2:30	5	0	0
“	318....2:30	3	1	3
“	1230....2:31	4	2	8
“	1465....2:33	2	2	4
“	318....2:33	3	0	0
Pennsylvania R. R.,	8242....2:35	1	4	4
C. & N. W. Ry.,	318....2:36	7	1	7
“	1230....2:35	3	0	0
“	1230....2:38	3	2	6
C. M. & St. P. Ry.,	5503....2:39	4	2	8
C. & N. W. Ry.,	1499....2:42	1	1	1
“	318....2:44	2	0	0
Pennsylvania R. R.,	8097....2:45	4	4	16
C. M. & St. P. Ry.,	........2:49	3	2	6
C. & A. R. R.,	95....2:50	3	4	12
C. & N. W. Ry.,	........2:52	3	3	9
“	........2:52	3	2	6
“	1109....2:53	2	3	6
B. & O. R. R.,	2372....2:55	1	1	1
C. M. & St. P. Ry.,	257....2:55	18	0	0
Pennsylvania R. R.,	8538....2:58	13	0	0
	Total	190		217

This hour's work totals thus:

RAILROAD.	STACK MINUTES.	SMOKE UNITS.	PERCENTAGE OF DENSITY.
C. & N. W. Ry	101	124	24.6
C. M. & St. P. Ry	47	48	20.4
Pennsylvania R. R.	18	20	22.2
C. B. & Q. R. R.	20	12	12.0
B. & O. R. R.	1	1	20.0
C. & A. R. R.	3	12	80.0
Totals	190	217	22.8

TABLE III.

Density of Locomotive Smoke

(Within Chicago City Limits)

Listed According to Location.

DATE.		LOCATION.	PERCENTAGE OF SMOKE DENSITY.
October	3rd	At 63rd st. and Illinois Central R. R. tracks	12.27
"	4th	At 16th st. and the Lake Shore Railway	20.94
"	5th	At 16th st. and the Pennsylvania Railroad	17.1
"	6th	At the Santa Fe & Penn. crossing, 19th st. and Stewart ave.	24.1
"	7th	At the C. & N. W. and Chicago T. T. crossing, at Rockwell st	19.1
"	8th	At the C. B. & Q., the C. & N. W. and the C. T. T. at Ashland ave	39.9
"	10th	At the Illinois Central R. R. at Van Buren st.	10.5
"	11th	At C. & N. W. Ry. at Kedzie ave	26.5
"	12th	Holiday	....
"	13th	At C. & N. W. Ry. at Madison st	22.4
"	14th	At Pan-Handle crossing at 26th st	30.5
"	15th	At Santa Fe and Pan-Handle crossing	32.3
"	17th	At Ashland ave. and C. J. R. R	34.4
"	18th	At 47th st. and Center ave	32.0
"	19th	At Halsted st. and 49th, G. T. R. R	39.8
"	20th	At 55th st. and C. & W. I. R. R., south end of Erie yards	45.4
"	21st	At Halsted and 40th, C. J. R. R	29.2
"	22nd	At U. S. Yards, main gate, 43rd & C. J. R. R.	27.0
"	24th	At Pan-Handle & C. M. & St. P. Ry., at Desplaines st	23.3
"	25th	At Pan-Handle & C. M. & St. P. Ry., at Ada st.	23.1
"	26th	At C. M. & St. P. Ry., at C. & E. Junction	22.3
"	27th	At C. M. & St. P., at Belmont ave	12.9

October 28th	At C. M. & St. P. Ry., at Pacific Junction....	25.2
“ 29th	At C. B. & Q. R. R., at Harrison st..........	16.7
“ 31st	At C. R. I. & P. Ry. and Lake Shore, at Root st.	27.28
November 1st	At Pan-Handle and Chicago & Alton crossing.	33.78
“ 2nd	At Halsted and 75th sts....................	27.82
“ 3rd	At C. & N. W. roundhouse, Chicago ave. and Halsted st.	22.6
“ 4th	At C. B. & Q. roundhouse, 12th and Canal sts..	27.14
“ 5th	At B. & O., C. T. roundhouse, 12th st. and the River	19.18
“ 7th	At C. M. & St. P. roundhouse, Chicago & Grand avenues	26.95
“ 8th	Holiday.	
“ 9th	At C. G. W. roundhouse, 46th and Colorado avenue	28.3
“ 10th	At C. & W. I. roundhouse, 51st st. and C. & W. I. R. R..........................	27.2
“ 11th	At Grand Trunk roundhouse, 49th st. and Kedzie ave.	35.23
“ 12th	At C. & N. W. roundhouse, 40th ave..........	33.53
“ 14th	At I. C. R. R., at Randolph st...............	12.8
“ 15th	At M. C. Roundhouse at 16th st. and Indiana ave.	16.71
“ 16th	At C., R. I. & P., 47th st. and Wentworth ave.	26.6
“ 17th	At L. S. & M. S. roundhouse, 63d st. and Indiana ave.	12.58
“ 18th	At Illinois Central roundhouse, 27th st. and the Lake	13.23
“ 19th	At Pennsylvania roundhouse, 55th st. and Stewart ave.	19.03
“ 21st	At south end of La Salle station at Harrison st.	11.77
“ 22nd	At south end of Grand Central station, Harrison and 5th ave......................	11.06
“ 23rd	At south end of Dearborn station, Taylor and Dearborn sts.	11.81
“ 24th	Thanksgiving Day.	
“ 25th	At north end of Canal st. station, Madison and Canal sts.	11.05
“ 26th	At C. & N. W. Ry. station, Kinzie and Orleans sts.	13.0
“ 28th	At C., B. & Q. at Western ave................	18.18
“ 29th	At C. T. T. at Homan Avenue Yard...........	28.75
“ 30th	At B. & O. R. R. Yard at South Chicago......	29.51
Average	....	22.3

TABLE IV

Average Density of Smoke from Locomotives

(Within City Limits of Chicago)

October and November, 1910.

No.	Railroad.	October.		November.		Total.	
		Observations	Percentage of Density.	Observations.	Percentage of Density.	Observations.	Percentage of Density.
1	Wisconsin Central Ry.	30	19.6	72	9.8	102	10.76
2	L. S. & M. S. Ry. ...	116	19.5	564	13.88	680	14.43
3	Ill. Cent. R. R........	490	12.39	877	15.20	1,367	14.50
4	A., T. & S. F. Ry.....	50	20.8	40	8.6	90	15.42
5	Mich. Cent. R. R......	127	15.44	160	17.8	287	16.92
6	Pere Marquette R. R..	17	33.33	109	16.95	126	18.01
7	Wabash R. R.........	69	28.	98	15.4	167	19.94
8	N. Y., C. & St. L. R. R.	118	24.54	52	14.48	170	20.95
9	C., M. & St. P. Ry....	771	19.4	469	21.9	1,240	21.
10	C. I. & L. Ry.........	39	31.87	29	13.33	68	21.35
11	C. & E. I. R. R........	38	25.27	69	20.	107	21.9
12	Penna. R. R..........	643	23.6	449	21.65	1,092	22.6
13	Erie R. R............	64	28.45	35	16.34	99	23.61
14	B. & O. R. R..........	102	20.58	294	24.34	396	24.01
15	C. & N.W. Ry........	632	23.07	752	24.94	1,384	24.07
16	C. I. & S. R. R........	22	28.	47	22.7	69	24.09
17	C., B. & Q. R. R......	363	26.5	626	22.97	989	24.16
18	C., R. I. & P. Ry......	110	29.78	454	25.46	564	25.96
19	Belt Ry...............	96	33.2	351	23.88	447	26.02
20	C. G. W. R. R.........	52	26.6	191	26.41	243	26.43
21	C. & A. R. R..........	113	25.8	90	33.56	203	28.52
22	Ill. Northern Ry......	61	31.06	10	17.14	71	29.35
23	C. T. T. R. R.........	114	29.41	289	29.69	403	29.57
24	C. & W. I. R. R.......	38	36.1	19	17.77	57	30.26
25	Grand Trunk Ry......	101	36.7	209	31.6	310	32.38
26	Chicago Junc. Ry.....	298	42.9	28	28.66	326	41.78
	Roads having less than 50 observations—						
1	C. & O. R. R.........	1	80.	6	7.5	7	8.61
2	E., J. & E. (and C., L. S. & E.) Ry.....	3	36.66			3	36.66
3	Chi. River & Ind. R. R.	35	55.			35	55.
4	Manufactur's Junc. Ry.			1	60.	1	60.
	Total.............	4,713	24.27	6,390	21.17	11,103	22.30

TABLE V

Average Density of Smoke from Locomotives

Out of Town Observations—Listed According to Railroads.

No.	Railroad.	Observations.	Percentage of Smoke Density
1	L. S. & M. S. Ry...........................	7	17.14
2	Pere Marquette R. R......................	14	30.77
3	C., M. & St. P. Ry........................	494	31.07

DATA ON RAILROAD TRACKS – LOCOMOTIVES & COAL
COMPILED DURING SUMMER OF 1910

	RAILROAD COMPANY	MILES OF TRACK IN CITY LIMITS			LOCOMOTIVES									COAL					
					AVERAGE NUMBER IN CHICAGO AT ONE TIME			TOTAL NUMBER OF DIFFERENT LOCO'S IN CHICAGO DAILY			TOTAL NUMBER OF DIFFERENT LOCO'S IN CHICAGO WEEKLY			TONS PUT ON ENGINES IN CHICAGO DAILY			TONS BURNED WITH IN CITY LIMITS DAILY		
NO	TRUNK LINES	MAIN	SIDE	TOTAL	PASS.	FREIGHT	TOTAL	PASS.	FREIGHT	TOTAL	PASS	FREIGHT	TOTAL	PASS	FREIGHT	TOTAL	PASS	FREIGHT	TOTAL
1	A.T. & SANTA FE R.Y. CO.	13.28	43.82	57.10	10	24	34	10	24	34	19	35	54	52	158	210	25	75	100
2	BALTIMORE & OHIO R.R.	16.14	25.67	41.81	5	20	25	10	32	42	10	32	42	65	195	260	19	56	75
3	CHICAGO & WESTERN INDIANA R.R.	50.32	99.71	150.03	3	—	3	3	—	3	3	—	3	30	55	85	30	55	85
4	CHICAGO & ALTON R.R.	14.22	32.60	46.82	5	19	24	10	23	33	10	23	33	85	232	317	9	134	149
5	CHICAGO BURLINGTON & QUINCY R.R.	11.34	80.17	91.51	20	73	93	41	73	114	59	100	159	150	300	450	50	215	265
6	C & O R.R.CO. OF IND. FORMERLY C C & L	—	—	—	2	3	5	2	3	5	2	3	5	12	21	33	1	6	7
7	CHICAGO & EASTERN ILLINOIS R.R	—	—	—	8	12	20	12	13	25	12	13	25	19	58	77	24	52	76
8	CHICAGO GREAT WESTERN R.R.	—	16.01	16.01	4	12	16	5	20	25	5	20	25	32	100	132	15	48	63
9	CHICAGO INDIANAPOLIS & L'VILLE R.Y.	—	—	—	4	3	7	6	5	11	6	5	11	—	8	8	4	10	14
10	CHICAGO IND & SOUTHERN R.R CO	—	—	—	2	2	4	3	4	7	3	4	7	18	32	50	1	8	9
11	CHICAGO MILWAUKEE & ST PAUL R.Y.	54.66	109.01	157.67	18	76	94	34	96	130	56	145	201	172	598	770	49	457	506
12	CHICAGO & NORTHWESTERN RAILWAY	68.89	234.34	303.23	135	188	323	135	188	323	135	188	323	500	1500	2000	264	786	1050
13	CHICAGO ROCK ISLAND & PACIFIC R.Y.	35.94	76.99	112.93	17	17	34	33	27	60	222	166	388	52	158	210	88	118	206
14	ERIE RAIL ROAD	—	—	—	4	9	13	6	14	20	11	34	45	43	70	113	11	73	84
15	GRAND TRUNK RAILWAY SYSTEM	17.04	26.25	43.29	4	16	20	8	25	33	8	25	33	53	137	190	20	60	80
16	ILLINOIS CENTRAL RAIL ROAD	143.00	167.63	310.63	67	81	148	70	106	176	70	106	176	502	400	902	300	200	500
17	LAKE SHORE & MICH SOUTHERN R.Y.	11.42	73.85	85.27	22	43	65	26	48	74	181	324	505	180	383	563	78	231	309
18	MICHIGAN CENTRAL RAIL ROAD	7.58	42.60	50.18	5	18	23	15	20	35	15	20	35	44	131	175	22	68	90
19	NEW YORK CHICAGO & ST LOUIS R.R	8.70	29.51	38.21	4	22	26	6	25	31	6	25	31	35	112	147	10	55	65
20	PENNSYLVANIA RAIL ROAD CO	89.72	164.19	253.91	19	126	145	35	153	188	245	1071	1316	80	567	647	80	567	647
21	PERE MARQUETTE RAIL ROAD	—	—	—	5	4	9	8	2	10	52	3	55	30	20	50	10	20	30
22	WABASH RAILROAD	9.84	28.68	38.52	3	18	21	10	18	28	10	30	40	60	140	200	15	75	90
23	MINN. ST.P & S. STE M RY LEESES OF W C	—	—	—	6	9	15	6	9	15	6	9	15	—	6	6	13	39	52
	BELT OR TRANSFER RAILROADS																		
1	B & O CHICAGO TERMINAL R.R	33.93	50.77	84.70	2	23	25	2	23	25	2	23	25	19	57	76	25	75	100
2	BELT RAILWAY OF CHICAGO	32.24	66.36	98.60	—	82	82	—	82	82	—	82	82	—	425	425	—	425	425
3	CHICAGO JUNCTION RAILWAY	5.80	4.20	10.00	—	37	37	—	37	37	—	37	37	—	296	296	—	296	296
4	CHICAGO RIVER & INDIANA R.R	—	—	—	—	4	4	—	4	4	—	4	4	—	32	32	—	32	32
5	CHICAGO UNION TRANFER R.Y	—	—	—	—	1	1	—	1	1	—	1	1	—	—	—	—	2	2
6	CHICAGO WEST PULLMAN SOUTHERN R.R	—	—	10.00	—	10	10	—	10	10	—	10	10	—	40	40	—	40	40
7	CHICAGO & CALUMET RIVER R.R	2.19	.10	2.29	—	2	2	—	2	2	—	2	2	—	6	6	—	6	6
8	ELGIN JOLIET & EASTERN R.Y.	3.52	15.73	19.25	—	45	45	—	45	45	—	45	45	—	121	121	—	121	121
9	INDIANA HARBOR BELT R.R	10.25	—	10.25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	ILLINOIS NORTHERN RAILWAY	12.25	—	12.25	—	5	5	—	5	5	—	5	5	—	24	24	—	24	24
11	MANUFACTURER'S JUNCTION R.Y.	—	1.16	1.16	—	3	3	—	3	3	—	3	3	—	9	9	—	9	9
12	UNION STOCK YARDS	17.31	129.37	146.68	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	TOTAL	669.58	1512.72	2192.30	374	1007	1381	496	1140	1636	1148	2593	3741	2253	6391	8624	1463	4438	5601

4	C. & N. W. Ry	229	31.2
5	C., B. & Q. R. R	618	36.97
6	Grand Trunk Ry	40	40.0
7	Indiana Harbor Belt R. R	35	40.54
8	Ill. Cent. R. R	429	42.48
9	C. T. T. R. R	14	43.53
10	Mich. Cent. R. R	117	43.75
11	C., R. I. & P. Ry	253	44.38
12	Erie R. R	71	47.66
13	C. & O. R. R. (of Indiana)	8	48.0
14	C. I. & S. R. R	325	48.53
15	C. & A. R. R	196	49.36
16	C. I. & L. Ry	53	50.0
17	A., T. & S. F. Ry	241	50.02
18	E., J. & E. (and C., L. S. & E.) Ry	57	50.98
19	N. Y., C. & St. L. R. R	34	52.56
20	Wabash R. R	31	54.40
21	C., C., C. & St. L. Ry	87	54.51
22	B. & O. R. R	11	61.90
23	Penna. R. R	2	80.0
	Total	3,366	41.1

TABLE VI

Average Density of Smoke from Locomotives

Out of Town Observations—Listed According to Towns.

No.	Town.	Observations.	Percentage of Smoke Density.
1	Elgin, Ill	607	31.4
2	Aurora, Ill	483	32.9
3	Mendota, Ill	282	42.8
4	Kankakee, Ill	417	44.5
5	Harvey, Ill	170	44.9
6	Hammond, Ind	501	45.4
7	Joliet, Ill	540	47.3
8	Streator, Ill	366	51.0
	Total	3,366	41.1

Discussion.

President Chamberlain: The subject of the suppression of smoke has engaged the attention of the residents of Chicago and vicinity for many years. As is well known, the city authorities have been making considerable effort to reduce to a minimum the troubles due to smoke, and the speaker who has addressed us this evening gave us last year the history of the work that he has been doing for the suppression of black smoke in Chicago. Tonight the paper which is before us deals particularly with the locomotive smoke of Chicago.

Paul P. Bird, M. W. S. E.: The paper that I present to you this evening outlines an investigation which has recently been made by the Smoke Department of the city. This investigation has been a very interesting one and personally I have a good deal of confidence in the figures that are presented in the paper. For years it has been an open question as to what percentage of the total smoke of Chicago is made by the railroad locomotives. During the first year that I was Smoke Inspector, I often stated that I thought the railroads made smoke about in proportion to the coal burned; but as I came to think of it more and to analyze the subject closer, I came to the conclusion that they made a great deal more smoke, ton for ton of coal, than the stationary plants. As soon as we could get to it we undertook this investigation.

Wm. B. Jackson, M. W. S. E.: I have listened to this paper with a great deal of interest and there are a couple of questions that I would like to ask Mr. Bird. One is whether he has worked out any plan by which he can determine the relative deleterious effect of smoke which is given out at an elevation such as the average stack on a building or a factory, and the smoke as given out by a locomotive. The other question is, what is the effect, or how much difficulty does the exhausting of steam with the smoke on steam locomotives occasion in the use of the Ringlemann chart?

Mr. Bird: In reply to Mr. Jackson's first question, I will say that we have never worked out any means for determining the relative deleterious effect of smoke given out by stacks at different elevations. We of course appreciate that the smoke from a stack say 150 feet high is often carried long distances and is greatly diluted before it comes in contact with anything that it can damage. On the other hand, the smoke from locomotives, being discharged into the atmosphere so close to the ground, is of great damage to property near the right of way.

President Chamberlain: It occurred to me, in reading this paper, that there might be a difference in observations depending on the distance of the observer from the stack. It would seem, if the chart is held at a distance of 50 ft., and it produces a condition of grayness, that it would be modified to a certain extent by the distance of the stack under observation from the observer. For instance, if the observer were at a distance of a quarter of a mile from the stack, would not the appearance be less black than it would if he were within a distance of 200 ft.? Would not that difference in distance affect the reading somewhat?

Mr. Bird: I think it would not affect the reading very much. Our men have good, average eyesight, and they watch a locomotive as long as it is within reasonable distance. Take a Ringlemann chart at 50 ft., another at 75 ft., and another one at 100 ft. I doubt if there would be any difference in the way these three charts would look to the observer. We were careful not to record observations in this investigation unless the observer was within a reasonable distance of the locomotive.

President Chamberlain: Mr. Bentley, Assistant Superintendent of Motive Power of the Chicago & Northwestern Ry. Co., is here this evening. We would be glad to hear from him.

H. T. Bentley (Asst. S. M. P. & Mchy., C. & N. W. Ry.): I received an invitation from Mr. Bird to be here this evening and also one from your president, and I am very glad to be here.

I have looked the paper over as carefully as I could in the short time that it has been before me, and find that a tremendous amount of work has been necessarily done to frame up the enormous amount of data that is presented. I am not in a position to concur in all the conclusions reached; it is a big problem and there is no question but that two or three inaccuracies have crept in. I have been interested in the smoke problem for a number of years, and it is my judgment that during the past three to four years the Smoke Department and the railroad companies of the city of Chicago have made great strides in the reduction of the smoke nuisance, and I believe that everybody recognizes how much smoke is being emitted, and will do, and are doing, all that is reasonable or possible under the present conditions to reduce it to a minimum.

The question has been raised as to whether a stack say 5 ft. in diameter would not emit a larger volume of smoke than a locomotive having a stack 15, 16, or 17 in. in diameter, and whether the Ringlemann reading would simply give the density of the smoke and would not give the volume; whether the volume as well as the density should not be taken into consideration.

We are throwing a good many cinders out of the stacks of our locomotives, and it is like some other things that fall upon the just and unjust alike; most of them we get back on our own railroad tracks, but some of them, of course, do go out on the street.

In looking over the paper I notice that most of the observations have been made at points where the most smoke would be likely to occur, namely, at railroad crossings and places where an engine might have to stop when it was least expected, and the fire would be in condition to take the train through without a stop, but on account of blockage or signals being against the train the engine would have to shut off, and more smoke would probably be emitted at those particular points than at other points.

When we talk about 10,000,000 tons of coal being consumed in a year by the city of Chicago, it is difficult to grasp the meaning of those figures, and I think that probably they are as nearly accurate as it is possible to get them.

The Chicago & Northwestern Ry. Co., like a good many other railroad companies, have been battling with this problem for a good many years, and whenever a suggestion is made of a device, either patented or otherwise, that will possibly reduce the amount of smoke emitted, they are always willing to try it. In doing that, they have had the help of the Chief Smoke Inspector and his assistants, who have given valuable advice, both in locomotive practice and in stationary plants. Under the present conditions, where a new boiler has to be installed, before it can be installed a permit has to be obtained not only from the City Boiler Office but from the Smoke Department, and valuable assistance and ideas in the way of arranging the furnaces so as to get the best results have been received. We have always been very glad to take advantage of the information furnished us.

We have just addressed a letter (a copy of which is given below) to all our engineers and, in fact, every employee who runs into or works in the city of Chicago or has anything to do with the handling of coal, and by disseminating this letter among our own men we have appealed to their pride to obtain improved conditions and to co-operate with us and with the City Smoke Inspection Department, to reduce the smoke nuisance to a minimum.

The letter has been in circulation only a few days, and I am not yet prepared to say how the men are responding to the request, but I believe that by appealing to their pride and asking their assistance we will get better results than we have been getting in the past.

CHICAGO & NORTH WESTERN RAILWAY CO.
DEPARTMENT OF MOTIVE POWER AND MACHINERY.
Chicago, December 29, 1910.

NOTICE TO ALL EMPLOYES.

At a meeting of our Smoke Inspectors and other officials with Messrs. Bird and Harris of the City Smoke Department recently, the question was discussed by all concerned as to what could be done to further reduce the amount of smoke coming from our locomotives, roundhouses and other places where smoke is likely to be emitted, and it was stated that some observations and tests had been made by the City Inspectors to determine the average density of smoke emitted by engines of the roads running into Chicago. By the method pursued everybody concerned is treated absolutely fair, so that the road operating a large number of engines would have an equal opportunity of making a good showing as the one only using a few, the percentage of smoke density emitted in these observations taken being the basis for the results obtained, and while it is a fact that we burn more coal daily in the City than any other road and as a result make more smoke, we are not quite at the bottom of the list so far as density is concerned, but so near it that we are getting alarmed at the downward movement we are making in our efforts to reduce the nuisance. Nearly all of the large roads operating engines in the City are ahead of us. In October we stood 8th on the list out of a total of 29 running into Chicago, which was bad enough but in November we dropped to the 22d place or practically to the bottom; the men on the principal roads doing very much better than we did. Our General Officers from the President down are very much interested in the efforts being put forth by the City Smoke Department to reduce the amount of smoke emitted and it is only by your assistance that the results looked for can be obtained.

We believe our men are just as competent as any others in their method of handling engines, and when they are informed as to what is going on, will readily respond and make special effort, by careful working of engine, firing, attention to operating blower, smoke jets, and fire-box door, to reduce the amount of smoke to the greatest possible extent. Several cases have recently been brought to our notice of engines smoking badly while standing still, and no effort made to open blower valve or fire-box door, which, if done, would have at once overcome the nuisance. These were simply cases of inattention and should have never occurred. A place where we have been justly criticized is at clinker pits. Hostlers in charge of engines must give the question of smoke prevention the same attention that men operating in the Terminals are expected to do, and wherever smoke is likely to be emitted, whoever is responsible must take prompt action and stop it.

We have told the Chief Smoke Inspector and his assistants that we intend being Number One on the list from now on, and are, therefore, taking this opportunity of asking your assistance and co-operation to enable us to keep this promise. Will you not give it, and form yourselves into committees to help the Smoke Department get results?

R. QUAYLE,
Superintendent Motive Power and Machinery, Chicago, Ill.

C. A. Seley (Mech. Engr., Rock Island Lines): I have had but limited time to study the aspects of the smoke question, as presented by Mr. Bird in his paper, due to the short time the paper has been in my hands.

At a meeting of the Western Railway Club in November, 1909, Mr. Bird made the following statement: "As to the exact proportions of Chicago's smoke that is made by locomotives, it is a very hard thing to even make an estimate of. It is largely a matter of opinion."

It would now seem as though Mr. Bird believes that he has reduced the matter to an exact science and in doing so he finds the railroads as the chief offenders in the making of Chicago smoke.

For aiming at correct conclusions there must be correct data, and as the factors in this case are arrived at by estimates and observations which may be more or less accurate, it must be admitted that the conclusions are not based on fully proven data.

I will not question the distribution of the annual consumption shown on page 276, further than to say that each of the items are estimated and could hardly be arrived at otherwise. The item of railroad coal is said to be accurately estimated, because made by the railroads, but we decline the compliment for the following reasons:

It should not be a difficult matter to obtain data of the amount of coal used in a stationary boiler plant or any number of them for that matter, provided one has access to the accounts, but for locomotives the question is complicated, on account of the movement. Take any railroad, for instance; the Chicago city limits are from nine to twelve miles from the railway depots. Every through train, most of the suburban trains, and many transfer trains of freight cross the line daily, and the proportion of coal actually burned within the city limits is very difficult to estimate. Some of these engines are housed within the city limits, bring their trains down to the depot and in a half hour are out of the city again. Others arrive from outside, then take their train to the yard and go out of service, possibly until the following day. Some switching engines are in continuous service within the city limits, while others are not. Railway accounts are made up for the Terminal Divisions, which extend beyond the city limits, and no distribution is made with reference to whether they are in the city limits or not, so that again it is all a matter of estimate with us.

Not only is this true of the coal consumed within the city limits, but of the number of engines within the limits at one time, so that there are two variables in the estimate. The influence of these, as regards Mr. Bird's paper, may be shown by analyzing some of the figures on the last page of the paper. The total number of engines in Chicago at one time, divided into the total tons burned daily, gives about four tons per engine per day. The individual roads quoted run from 1.4 to 28 tons per engine per day.

On page 278 it is stated that a special observer made over 11,000 observations of the density of locomotive smoke in October and November, 1910. Assuming fifty-two working days in that period and eight hours per day, would make 26.4 observations per hour. As many hours and perhaps days have weather that will not permit accurate comparative observation, the rate must have been much higher than the figure above named.

It may not be denied that observations of a stationary stack can be taken for as many minutes as may be desired and the smoke density classified by the Ringlemann charts. The observer and the stack are in a fixed relation, but with a moving locomotive the distance attained from the observer in the one minute may be as much as one-half mile, and, no doubt, many of the 11,000 observations were long distance records. The point of observation is stated to be frequently at junctions of two or more railroads. Everyone knows that such points are always approached with caution and frequently stops are required, and it is impossible under such conditions to as fully control the fires and smoke as at other points. As a matter of fact, Table III of location of points of observation shows mainly points where such adverse conditions obtain rather than a fair average over the entire line within the city limits, and explains the high percentage of smoke density to a considerable degree.

Another feature that is apparent from analysis is that of surroundings. The smoke densities on the lake front are very low, as compared with all others, indicating that the background of the lake influences the observation as compared with those taken where the atmosphere is already laden with smoke from other sources. I do not believe that my good friends on the Illinois Central Railroad will claim to have any better engines or appliances than we have. Many of them are identical in design and operation, and the men are under practically the same rules and instructions. The coal is practically the same, and yet the roads away from the lake front and among other sources of smoke production are shown with greater percentages of smoke density. These features, together with the lack of opportunity for a continuous observation with a fixed relation of the observer and the locomotive, leads to the conclusion that the statements made as to density are not fair to the railroads. Even if they were, they are in regard to a machine that in most cases is in the city for a limited number of hours, is out of commission and smokeless often for many hours of the twenty-four when in the city, is never worked continuously to capacity for any great length of time, yet its record when at work is compared with stationary plants of all kinds, nearly all of which are in continuous operation. In other words, the smoke density of a locomotive which is in service in the city one-half hour of the twenty-four has the same record as if it was operating continuously, so far as these statistics are concerned.

It is believed that the statement on page 283 as to the amount of cinders thrown from stacks of locomotives, is overstated. There are only a couple of testing plants in this country where experiments have been made to ascertain the amount of cinders passing out of stacks and even these are not exact. During the St. Louis Fair of 1904 the cinders discharged from the stacks and those caught in the front ends amounted to about 10% of the total weight of fuel burned. These engines were worked at full capacity at various speeds, whereas the engines in Chicago are working at full capacity for only a portion of their time, so that 10% is entirely too great. This is particularly true of switch engines, where actual mileage per day is very low, and this class of engines is predominant in the city. The throwing of cinders is probably greatest on suburban engines, which make numerous stops and have to accellerate rapidly.

Although, as stated, I disagree with the conclusions in Mr. Bird's paper, believing that the railroads do not make the proportion or density of smoke credited to them, I do agree to the principle of smoke regulation insofar as it can be economically enforced and with due regard to the public health and comfort. Furthermore, I believe that the railroads are generally of that opinion and are endeavoring to co-operate with the city to that end. My use of the word "economy" is in the broad sense. Pittsburg could not make steel for the world and be a smokeless city, neither can Chicago be the distributing point and clearing house of industry of the middle west and be a smokeless city. True economy means a wise use of our natural resources and a checking of waste. The steam locomotive, as Mr. Bird truly says, is a highly developed machine and, contrary to what many people think, is a highly economical machine. The locomotives in this country, except a few in the anthracite territory or where oil is available and cheaper than coal, use soft coal and make more or less smoke. Pocahontas coal is cited as making less smoke than others, which is true, but would the business interests of our vicinity regard the use of Pocahontas coal on locomotives as of economic advantage to the community at large?

The expenditures of Chicago railroads for fuel should go to build up the business interests of Illinois and Indiana rather than of Virginia.

Considerations of economy in this sense, therefore, lead us to use present fuels, but in connection with approved appliances and constant vigilance to keep the smoke to a minimum.

Allusion is made in the paper to electrification as the panacea, "the only final and satisfactory solution of the smoke problem."

This is a large question and a debatable one, and I can only touch on a very few points. Although fifteen months have passed, I see no reason to change the views expressed in a paper which I read before the Western Railway Club in November, 1909. I invite you to consider the situation in Boston. That city rather than New York is similar to Chicago as regards electrification requirements. It has water on one side and radiating lines of passenger railway tracks of about 600 miles within the district, and it is estimated that it would cost $39,000,000 to electrically operate passenger traffic over these rails. Freight and switching movement have not been considered. Boston recognizes that it would have to pay for that electrification in increased fares or rates and after consideration of the question by a commission of sixteen members and the two railroads involved, it was decided by nine members of the commission that as a result of their conclusions it is not wise nor in the public interest to exact legislation compelling any electrification of railroads. A minority report of five members dissented from the above to the extent of recommending legislation that would require a commencement of actual work of electrification at a date to be fixed by the general court or some public agency designated to extend the time for good cause shown.

NOTE:—

A summary of the conclusions reached by the Massachusetts Joint Board on Metropolitan Improvements is given as follows:

Electrification is desirable on account of comfort and convenience of the public and some advantages to the railroads.

Best methods are still undetermined.

Electrification of terminals under the present conditions does not result in economy but increases expense, aside from the interest incurred.

If greatly increased traffic would result from electrification, the expense would be reduced.

Electrification would oblige railroads to make charges to operating expenses, due to property abandoned or replaced in addition to interest on new capital and increased expense of operation.

Electrification would require an increase of passenger fares to produce the revenue to pay for it.

Electrification, while desirable, is not necessary nor required on the grounds of public safety.

To compel electrification would postpone other expenditures demanded by considerations of increasing traffic, etc.

Railroads are already hampered in obtaining capital by other regulations of the State and Government.

As a result of the foregoing conclusions, the Board believes that it is not wise nor in the public interest to enact legislation compelling any electrification of railroads.

Boston passenger and suburban traffic is nearly three times that at the Grand Central Station, New York City, and the number of lines, as compared with New York, makes the expense in Boston much greater than in New York. This is a consideration which would also rule in Chicago.

It is believed that rates should be raised for both passenger and freight traffic to provide necessary capital if both classes of traffic are required to be moved electrically.

Such increase in rates should be borne by Boston business interests and might add to their disadvantages.

The benefit of electrification in Boston will accrue mainly to commuters and short distance traffic, and owners of property along the lines electrified. An increase of suburban fares will discourage the development of suburban territory and divert travel.

For reasons connected with evolution of electric traction, also the demands for increasing traffic in other directions, it is believed that these matters should be allowed to work out themselves without legislative enactment.

Calls attention to the partnership of the public in all such improvements without risk, and its attitude should be to encourage a legitimate and economical expenditure of capital with fair compensation.

A second minority report signed by two members dissented from the above idea of any compulsory legislation or any definite datum but would require continuance of investigations and studies as to plans and estimates taking up the question of rates as well as costs.

According to Mr. Bird's figures, Chicago has about 670 miles of main lines, which compares closely with that of Boston and has in addition over 1,500 miles of sidings, all of which would have to be considered for complete electrification.

Can Chicago pay the price, as it will undoubtedly have to do if electrification is to be an accomplished fact on her railroads?

If the public can afford to pay the price for electrification of railroads, a certain degree of smoke and dirt reduction may be accomplished, but it is doubtful if the general atmosphere of Chicago would be greatly cleared. The enormous quantity of soft coal otherwise used is too great a factor.

As regards the matter of health, an examination of the death rate of various American cities does not put one in fear of a Chicago residence as being extra hazardous. The following cities have a higher death rate than Chicago: Boston, Buffalo, Cincinnati, Cleveland, Denver, Detroit, Jersey City, Kansas City, Louisville, Memphis, New Haven, New Orleans, New York, Philadelphia, Providence, St. Louis, Scranton, Syracuse, and many others, including that cleanest of all cities, Washington, D. C.

I have purposely omitted Pittsburg, which is also higher in death rate and most smoky of all, for the reason that there is a prevalence of hazardous occupations and a preponderance of foreign population, which is more difficult to handle, so far as sanitary regulations are concerned.

Many of the above named cities are notably free from smoke, as compared with Chicago, and perhaps not more so than other cities such as Indianapolis, Milwaukee. Minneapolis, Omaha, St. Paul, Toledo, and others which have a lower death rate than Chicago, so that death rate statistics do not appear to afford a direct charge against smoke as the factor controlling them.

J. F. DeVoy (Asst. Supt. Motive Power, C. M. & St. P. Ry.): I have some opinions based on experience as a testing engineer for the past twenty years. Before giving them I want to say that I have the highest regard for Mr. Bird personally, and that such criticisms as I shall offer will relate only to his work as embodied in this paper. I am going into the matter at length, because this paper, coming from a man of Mr. Bird's standing, will attract attention.

I feel safe in saying that the author of the Ringlemann system did not intend that it would be used in estimating the density of locomotive smoke. This paper contains a quotation from the Transactions of the American Society of Mechanical Engineers. On the page opposite the one from which this quotation is taken is a paragraph indicating clearly that the tests under consideration related only to stationary stacks. I quote a part of the first sentence: "In the series of competitive trials between two furnaces which the writer made in June, 1897, for the Detroit waterworks"—. This is taken from the report of the committee on the revision of the standard code for conducting steam boiler tests. No mention of locomotives is made in this report. To secure a correct estimate, tests of considerable duration are necessary. This is obviously impossible in the case of a moving locomotive.

Quoting again from this report: "A continuous record of the quantity of smoke was introduced, which seems to him to be of great value in making specific what has heretofore been based upon the judgment of the person conducting the observations."

A continuous record is considered necessary for reducing to reasonable limits the errors due to personal equation of the observer. What confidence, then, can be placed in fragmentary observations made on moving locomotives. Under the best of conditions there are serious differences of opinion among the observers. A great many men are color-blind, and it is my experience that no two men will judge of the density of smoke exactly alike. If the author of this paper had made these observations himself, I would have confidence in them. But he sent different men to make the observations, and there is no question in my mind that serious errors have crept in .

My first test was made in 1891 on the West Shore Railroad, under the supervision of Professor Carpenter, of Cornell University, who taught both Mr. Bird and myself. In these tests it was found that only 7.9% of the coal was thrown out.

In a test conducted by me personally, which has been reduced to figures by Mr. Prentiss, Chemical Engineer of the C. M. & St. P. Ry., the exact percentage of front-end cinders is found to be 2.9. You will understand that this was a fair test and was conducted along the lines specified by the American Railway Master Mechanics' Association. In looking over other tests that I have made, I find one in which this percentage was 5.6. Mr. Prentiss has stated that in the Pennsylvania tests the average was 4.4%. It is my experience that the average percentage of coal thrown out of a locomotive stack is about 4%. 10% as given in this paper is entirely too high.

The conclusion reached in Mr. Bird's paper is as follows:

> "The study that has been made along these lines indicates clearly that electrification offers the only final and satisfactory solution of the locomotive smoke problem."

I do not believe that the advocates of electrification realize what electrification means. Does Mr. Bird base his conclusion on the same inadequate data as were secured in the smoke investigation? In my opinion there will not be enough money in our time to accomplish this result. Electrification of Chicago terminals would require nothing less than an act of Providence.

The author of the paper speaks of electrifying freight terminals when no such thing has ever been done. In the present state of the art I believe it is an impossibility to electrify freight terminals.

If electrification by means of third rail transmission were attempted, it would result in continual and appalling loss of life among switchmen working in busy freight yards. I understand that Mr. Bird has a plan by which an overhead system of transmission is to be used. Nothing of this kind has ever been tried for freight terminals, and I am convinced that it would be commercially impracticable to transmit enough power in this way. I am familiar with the third rail systems and with the underground system in Washington, and do not believe that electrification of the freight terminals of Chicago can be accomplished in the present state of the art.

Furthermore, if the people of Chicago insist on electrification, they will have to pay for it in the end, for aside from earnings the railroad companies have no means of paying. The cost will be enormous—probably $500,000,000.

I feel justified in questioning the accuracy of the results obtained by Mr. Bird's investigation, since I have had 23 or 24 years of experience in that kind of work. In all, I have conducted something like 500 tests. In the tests where I obtained a percentage of 2.9 I was behind the locomotive on a dynamometer car for seventeen days and nights trying to ascertain, if possible, how we could prevent forest fires in Montana. I have spent a great part of my life on work of this kind, and considering the conditions under which Mr. Bird's investigation was conducted, I cannot agree with his results.

President Chamberlain: We are very glad that the representatives of the railroad companies have brought out their side of the question, and I am going to adopt Mr. Seley's suggestion now and call on one of our own members, who is as well posted on coal and smoke as any man in the United States. We would like to hear from Mr. Bement.

A. Bement, M. W. S. E.: I wish to say, so it may be a matter of record, that the presentation of this paper is an epoch in the matter of smoke suppression. It is a remarkable occasion when a Smoke Department presents a research of such character. I will say that, without question, the Smoke Department of no city in this country has attempted as thorough an analysis as this presented by Mr. Bird. Chicago has always had a better Smoke Department than any other city in the United States. Its department today is much better than preceding ones and we are to be congratulated on this fact. It is also well to have in mind that our Smoke Department has not only exercised a restraining and compelling influence, but has also rendered valuable assistance to coal consumers. It has been my experience that things we must necessarily do to bring about smokeless combustion of coal, are just the same things that we would do if the object were to secure better heat efficiency. The result has been that in a marked number of instances the Smoke Department, in its campaign for cleanliness, has been the means of saving money for the coal consumer. In one instance, at least, the enforcement of the smoke regulation in connection with locomotives in this city has resulted in a notable increase in heat efficiency and economy in fuel.

With reference to the question of quantity of cinders that are thrown from locomotive stacks, I will say that Dr. Goss, in the issue of the Journal of the New York Railroad Club which contains proceedings of the meeting held September 17, 1896, gives results of experiments to determine losses of this character.

Regarding the smoke made by rolling mills, to which Mr. Seley refers, I have in mind the Homestead plant of the Carnegie Steel Company at Pittsburg, which makes very little smoke, although it is a very large plant, consuming an enormous quantity of coal. This is because automatic stokers are employed, and illustrates how improvement is effected through the replacement of old and inefficient methods and appliances with modern apparatus, which not only stops smoke, but increases efficiency, resulting in a general economy.

I will refer briefly to a delicate phase of this matter,—that of electrification,—although I did not expect to say anything about it when I came here tonight. I do this because I feel it to be a duty. It is known that I have been a consistent advocate of smokeless combustion with coal, and that I have devoted considerable time and money in various ways towards its accomplishment. At the same time, I have always tried to be reasonable and practical. I have recognized that between two evils it is desirable to be burdened with the least objectionable one. If we cannot have factories without smoke, I think we should have factories and endure the smoke, but as long as we may have factories without smoke, there is no reason for enduring it, especially as the fact has been sufficiently demonstrated that factory and power plants, at least, can be operated under all conditions without making smoke, and with economy to the owner.

The problem with locomotives, however, is more difficult. Personally, I have been able to operate locomotives under every variety of condition, smokelessly;—on the road hauling heavy trains; suddenly shutting the throttle on a fresh fire; with heavy and light firing. With every kind of service it can be done by simply using the appliances already on the engine, and without the application of special devices. Such results are, however, obtained only by great care and watchfulness.

This is where the locomotive-smoke suppression proposition is weakest, and it is for this reason principally that electrification, as a cure for locomotive smoke, has been urged. The suggestion has not been received favorably by the railroads, although this is not strange, considering the expenditure of money that would be necessary to bring about that amount of electrification which appears to the railroad official to be demanded by the public. The result is a decided opposition, on the part of the railway officials, to electrification as a general proposition. This may lead to a disposition to overlook instances wherein electrification would be an economy to the railroads. If I have any suggestion to make in this connection, it is that railroad officials make electricity its servant in those instances where its service may be useful, rather than allow it to become its master in those matters where it not only might be useful, but burdensome as well.

Robert H. Kuss, M. W. S. E. (Chief Assistant Smoke Inspector, Chicago): I hardly expected to be called upon, and I do not know how to contribute anything of value to the discussion, especially as I am not well qualified to speak on any subject, much less the important one of solving the locomotive smoke problem.

Mr. Bentley criticizes the matter of observing a locomotive stack 14 to 18 in. in diameter and comparing the result of such an observation with a chimney 5 ft. in diameter. It happens that the shoe pinches the other foot, inasmuch as a chimney 5 ft. in diameter, delivering a certain smoke density, will be recorded by the Ringlemann chart system to be in far worse condition than would be attributed to a locomotive stack even when the actual density from both stacks is the same. The foregoing statement applies up to the point where the smoke coming from the stack of smaller diameter is recorded as delivering smoke less than maximum density. In other words, the observation is more than fair to the locomotive stack. From the standpoint of the railroad man there should be no criticism; if anything, the adverse criticism should come from some other direction.

The all-important paragraph of the paper is, no doubt, the one so often quoted in the discussion, that the electrification of railway terminals offers the only final and satisfactory solution of the locomotive smoke problem. Whether or not we all agree that electrification offers the only solution is not so important as that it offers one solution. The fact remains that all of the solutions thus far proposed have either failed in their trial or have no supporters, with the one exception of the electrification of the railway terminals, using the expression in the sense that central power stations are to supply the motive power and electric locomotives will exert the effort.

For my part I do not take the position that electrification as ordinarily meant is the only solution of the locomotive smoke problem, though I heartily agree that should this method be adopted the solution would be satisfactory to the public, and otherwise complete, considering smoke elimination. I have an alternate solution in mind which if adopted would be no less satisfactory from a smokeless standpoint and would perhaps offer other advantages. As there is no particular secret about it I may be pardoned if the fundamental items of the scheme are listed here. The system referred to would be conducted precisely as at present, with steam locomotives, except that the locomotives would be gradually replaced by others of a type incorporating the following essential parts:

1. An internal combustion engine of the Diesel type, capable of developing approximately the average horse-power of the service for which the locomotive is designed.
2. A direct-connected electric generator, the output of which is designed to agree with the engine output running at its most economical rating.
3. An electric storage outfit, capable of serving power for a suitable period of time, sufficient to exert a maximum effort equal to the power requirements of the locomotive when the engine and generator are out of service.
4. Motor-driven running gear.
5. Controlling apparatus capable of throwing into service the generator alone, the storage alone, or both together at any desired ratio of power delivery.

The advantages of such a system become apparent in that the central power plant and power transmission apparatus can be avoided. The type of engine mentioned is exceedingly economical, and the kind of fuel possible for use is of wide range; the engine is especially economical and satisfactory at constant load.

All of the essential parts of the system have already been developed; what is lacking at the present time is a suitable combination of the parts, a criticism that can be made just as well in regard to the system proposed by the paper. It is very true that before a suitable locomotive of the type mentioned could be produced, much time and money would have been expended. The trials that would have to be made would be discouraging, no doubt; likewise would the cost of the developed unit be high, even after having a satisfactory pattern to work by. The returns on the investment should be worth the expenditure, counting the cost of development. The system could be worked into use gradually, thereby obtaining the entire usefulness of the present equipment without an extraordinary scrap-pile loss. So far as the prevention of smoke goes, there could be no criticism; so far as the sentiment regarding the prevention goes, the people will be satisfied when they can look forward to an ultimate, permanent, and complete solution, and they are willing to be patient during the development of the system that assures such a result.

President Chamberlain: Mr. Kuss has presented the matter of electrification in what probably is a new light to some of us. When we are prone to prophesy as to what will happen in the way of railway development, locomotive development, I often think of the statements made fifteen or twenty years ago in regard to the motive power of the railroads of that time. I think that nearly all of the railroad men who are here will probably bear me out in the statement that most of the Superintendents of Motive Power fifteen years ago thought we had reached the limit in the size and weight of locomotives. I know that I heard a very prominent railroad man say that we had undoubtedly reached the limit in the weight of locomotives, and yet since that time we have built locomotives more than double the weight of any of them in use at that time, and the limit has not yet been reached. The demands of the railroad officials for the carrying of heavy tonnage over the road have developed this condition, and I do not know but that the demands for smokeless transportation in our cities will some time develop a system of electrification by which the problem will be solved.

Albert Scheible, M. W. S. E.: In regard to the point about the financial impossibility of electrification, I will merely suggest to some of our railway friends that they do not look up the records of the Electric Light Association of about twenty years ago, for otherwise they might find some strong statements to the effect that the proposed putting of wires, especially arc light wires, under ground would bankrupt the electric light companies. However, there may be other ways of mitigating the smoke nuisance.

I would like to know if anybody here is familiar with the way the Massachusetts law is working out. Some of you may remember that last summer a law went into effect in Massachusetts, to apply to Boston and vicinity, for restricting the amount or density of smoke and its duration, delivered by chimneys of various sizes. In that law there was a discrimination between the density afforded by chimneys of different sizes and between chimneys on different classes of devices; as, for instance, a 10 ft. chimney would be allowed to emit a density equal to the Ringlemann 3 or 4 for a longer period than a chimney only 4 ft. in diameter. This same law also provided that for locomotives it should be lawful during 1910 to emit smoke of a Ringlemann density of 3 for a period of forty seconds out of any five minutes, which period should be reduced during 1911 to thirty seconds, and after that to twenty seconds. In the case of locomotives drawing trains of six cars or more, the time was lengthened somewhat. If any one here knows whether that has been effective, it would be interesting to hear about it.

It may also interest some of the members to know that the agitation in Europe to cause the suppression of smoke has reached the stage where Germany now has a monthly magazine devoted purely to the suppression of smoke and dust.

P. M. Chamberlain: I have read the paper with a good deal of interest, and wish to make comment on the form of the paper, which impressed me most favorably, namely, the placing of the summary of conclusions at the beginning, which presents the ground that has been covered in the course of experiments and investigation, and is followed by the reasons and data which led to the conclusions. I note that in the summary of conclusions the matter of electrification is not mentioned. That item referred to seems to be an observation that the study which has been made along these lines indicates the sure cure in electrification. Bearing on some of the criticisms we have listened to, doubtless any of us could find fault with the various things which we find in records of investigation, but here is a paper which has been prepared by a man who has given several years of his attention to the matter of smoke, and it commands consideration.

The conclusions as to the percentage may vary. For instance, if the author and his department carried out similar investigations for the next ten months, they might find that the proportion varied some, but they have been giving the matter careful study and careful thought. They do not dogmatize in saying that this is the only possible proportion, but that careful study of the data causes the author of the paper to have great confidence in the results set forth in the paper, and as such it seems to me that it is a marked contribution to engineering knowledge.

H. Misostrom (Deputy Smoke Inspector): I beg pardon for intruding at the last moment, but I would like to make a few remarks particularly on the subject of the observations. I am quite well acquainted with the persons from whom the author obtained most of the observations, and I do not claim, nor does he, I presume, that they are perfect; but they are just, as comparative of the stationary plant and the railroad locomotive. From my personal knowledge, efforts have been made to be just to both. No partiality was ever shown and the investigation was not started with foregone conclusions of any kind.

Dr. W. A. Evans (Health Commissioner): I think the paper is admirable in intent, in plan, and in its results.

Not much accurate scientific work has been done on the harm of bad air. Not much has been done on air pollution nor on the importance of the different agencies in relation thereto. Here is a painstaking effort made along scientific lines to remedy some of these deficiencies. The city is to be congratulated upon this good piece of work done by a city department. No American city has so good a smoke department as Chicago.

One of the speakers quoted the Boston report on electrification and gave the membership of that commission. As he grouped the membership therefor, I saw a shortcoming which greatly weakened the report. The health side was not represented.

The question of traction by steam locomotives as compared with electric power is not properly weighed until the harm of smoke, and especially the disease, disability, and death which it causes is weighed in with the other economic factors, such as cost of installation, fixed charges overhead, ton mile cost, passenger mile cost, and effects on density of population. As we figure the cost of transportation, let us also figure the cost of smoke-caused consumption, pneumonia, and colds.

The gist of our success in the Panama Canal is that we have weighed the *health* factor and the French did not. Their engineering methods were much the same as ours. It was our health methods which spelled success for our project.

The gentleman from the C. R. I. & P. R. R. advanced an argument which should be answered. Inferentially it was that cities having a great deal of smoke had a low death rate, therefore smoke did not do much harm.

In the first place I do not know of any comprehensive study of the different degrees of air pollution of various American cities. Therefore the grading of cities as to air pollution is based upon vague ideas and general reputation. This may and may not be correct. It is certainly not scientific. On the other hand the figures cited were gross death rates.

If we draw conclusions as to the sanitary conditions of a town from the gross death rates, we are liable to be led into error. Before such conclusions can be drawn it is necessary to apply many correction factors. For example, Washington, D. C., has a large negro population. The death rate of a negro population is always high. A comparison of the death rates of Washington and Chicago must take into account the differences in the negro population as compared to totals in the two populations.

The high rate of Pittsburg was laid to accidents and to foreign peoples. The first is incorrect, as accidents in a general population do not materially influence rates. On the other hand, the Pittsburg rate is increased by its immigration movement. But how does the foreign population of Pittsburg compare with that of Chicago? So here is another correction factor to apply.

But what are the age periods of your foreigners and what are the normal death rates of your nationalities? For example, Poles have a high infant rate and a low consumption rate. Jews have a low infant rate and a high consumption rate. Slavs have a low infant rate and a high consumption rate. Is your city young, with large numbers of babies, in whom the rate is always high, or is there a large proportion of school children, young men and women, in whom the rate is always low; or is it a community of old retired people where the rate is always high?

I think I have said enough to demonstrate that conclusions as to sanitary conditions drawn from gross death rates are liable to be misleading.

While speaking of the errors that creep into the arguments of those who claim that smoke does no harm, I want to touch on two others. You may remember the rosy-cheeked official of the Firemens' Union who spoke against electrification before a council committee a while ago. He offered himself as Exhibit A. There are two answers to his argument: first, he has not fired an engine for many years; second, a fireman seldom gets much smoke. An engine cab is about the best ventilated place of which I know. A while ago a gentleman argued that a low death rate amongst miners was proof that smoke was harmless. The answer to this is, miners do not work in smoke. Mines are usually located in the country and the only engines around are those which run the elevators, pumps, and fans.

The coal dust of mines differs physiologically from volatilized coal called smoke. Mines are well ventilated and even the dust in many of them is kept down by sprinkling.

The gentleman from the C. M. & St. P. Ry. told us that electrification was impossible,—that it would kill large numbers of people. I have recently read the hearings on steam heating of railroad coaches. These hearings were held several years ago, and the statement was made that it was not possible to steam heat coaches. One reason advanced was the heavy mortality which it would cause.

During the presentation of this paper and discussion I sat here listening without thought of speaking. This is my excuse for discussing the *discussion* rather than the paper.

H. H. Evans, M. W. S. E.: In line with Mr. Bement's suggestion, I think it would be a good thing if the representatives of the railroad companies who are in position to obtain the figures could supply the number of accidents that have occurred on the electrified railroads in the country; these figures referred to a train mile basis over the terminal. Along with it perhaps would be interesting the number of accidents directly traceable to the operation of steam locomotives, in similar service, on a train mile basis. For three or four years I have been trying to get definite figures on this particular thing. I have heard a great deal of talk by one and another about the hazards of electrified roads and the great number of people that have been killed thereon. Not one of these persons has been able to give authoritative figures whereon to base his statements, and my own search has failed to reveal figures which would lead to alarming conclusions. What I did succeed in finding was this:

Mr. Wilgus, in his paper upon the New York Central electrification read before the American Society of Civil Engineers, stated: "During the period of a year and a half that the working conductors have been energized in the congested initial electric zone of the New York Central, not a fatality has occurred there to employees or the public primarily due to third-rail or transmission lines. Three instances have been due to trespassing on the transmission line, another to a porter reaching beneath the rail for a pack of cards, and one to a prior contributing cause."

On the *Valtellina,* a 67 mile main line electrification in Italy, in the first four years of operation, no one was injured on the line by the electrical apparatus. During this time the only fatality which occurred throughout the system was the killing of one of the men employed by the contractor who installed the system. This man was electrocuted behind a sub-station switchboard.

On the Lancashire and Yorkshire railroad in England, when first opened, a number of people were killed through contact with the third rail, but after the system was put in working order, for considerably over a year there was nothing in the nature of a serious electric shock or accident.

The Board of Trade returns, covering the electrifications in Great Britain for 1904-5-6 and to August, 1907, indicated 16 killed and 71 injured throughout Great Britain. Of the people who were killed in the four-year period, 4 were railroad servants and 12 trespassers. Of those injured, 40 were railroad men, 1 was a passenger, 5 were people on business with the railroad, and 25 were trespassers. Of these casualties, the Northeastern had 8 killed and 28 injured, and the Lancashire and Yorkshire had 5 killed and 19 injured. The 16 killed during the four-year period represent the casualties not only on the electrified railway systems in England, but on the various third-rail systems employed on elevated, subway, and other urban and interurban lines throughout Great Britain.

The Lancashire and Yorkshire electrification covers a track lay-out and service almost identical with that of the Illinois Central R. R., and if the Illinois Central should electrify and hold that ratio of 5 men in four years, that is, a little over a man a year, I do not think there would be any comment as to the terrible slaughter from electrification.

At the time that the New Haven electrification was put into service, under a Connecticut state law it was required that the apparatus be examined and certification made to the State Railroad Commissioners whether it would be safe or not for the traveling public, and you will find in the Connecticut state railway reports a certification by Mr. Corson, who made the examination, in which it is reported it is perfectly safe. I have examined the Connecticut Railroad Commission reports and also the Massachusetts reports covering the last few years, one state containing an extensive electrification and the other only a negligibly small one, and both show a slight increase in the number killed on the railroads with the electrified main line in Connecticut, but no more than you would find from the increased train mileage that has been put on. There is, however, no striking difference between the figures for Connecticut and Massachusetts on a comparative basis. The slaughter from electrification does not manifest itself in the Connecticut report. Unfortunately the components of the report are not segregated so that you can tell which of the men were killed by the electrical apparatus and which were killed by the operation of steam trains. We can merely see that the totals are not extraordinary.

Mr. Kuss's idea was interesting. I came across an attempt to work out a somewhat similar installation on the Western Railway of France,—I think about five or six years ago. What was known as the Heilman locomotive was built. It was a complete power plant on wheels. There were compound engines, two of them, which drove direct-connected generators, the engines and generators being carried in the body of the locomotive. There were motors on the axles. The installation as worked out was not altogether satisfactory; in fact, it was unsatisfactory, but I think it emphasized very largely Mr. Kuss's point of a great deal being necessary to know as to the proper proportions of such a machine. As I recall it, there were 1,200 horse power developed in the locomotive. It weighed 150 tons, cost somewhere around $55,000, and proved very expensive in operation. The principle, of course, was worked out in a small way in some of the gasoline electric cars. The St. Joe Valley Traction Company had such a car for a light railroad service. They have since turned the road, I understand, into an electric railroad. There they were testing possibilities of a fast frequent service, and so they got a gasoline electric car. The first one was straight gasoline electric. The second was provided with a storage battery to help over the peak loads, and also to help them when they got out on to the line and anything happened to the engine. The General Electric Company, I understand, now has a gasoline electric car. I should imagine the internal combustion motors, in numbers, on a terminal, though, would emit gases which would be quite as offensive as anything which a locomotive would emit.

M. E. Harris (Smoke Department): The hour is getting very late, and therefore I will take up but a moment of time. One of the speakers of the evening referred to the location of the Illinois Central tracks at Van Buren street, and mentioned the low percentage of smoke observed at that point. From the remarks made I think he decided that the proximity of Lake Michigan affected the observations. I want to call attention to the fact that inspections made in other places, under different conditions, showed very nearly the same percentage. These were made near some of the railroad stations, for instance, the south end of the La Salle Street station, and the ends of the Canal Street station;

the percentage of smoke was about the same as on the lake front.

As I was Mr. Bird's chief lieutenant in carrying out this investigation I feel that I ought to speak on this matter, to remove any impression that you may have as to unfairness or possible partiality that might have been shown. There was none. The whole investigation was carried out with a view of being absolutely fair with everybody; and while it happened that the Lake Front showed up as the cleanest spot in the city, it did so just because it was the cleanest, and daily investigation of that point will prove it to anyone who questions the statement. Furthermore, this very fact is borne out by the railroad company at the top of the list —the Wisconsin Central—with 10% smoke density or a little more. Most of the observations taken on the Wisconsin Central were not on the Lake Front, but on the St. Charles Air Line and westward through the middle of the city. Yet that road presented the very best record. The Wisconsin Central happens to be a railroad that, so far as my recollection goes, has never been sued by the Smoke Department for violating the smoke ordinance. If any of you can equal that record you will have no more trouble than the Wisconsin Central has; that is the thing that all railroad companies should strive for, and that is the standard to which the Smoke Department is trying to bring the different railroad organizations. If you can equal the performance of the Wisconsin Central Railroad, the Smoke Department will not use many postage stamps in sending you notices.

Mr. Seley: I have had this chart on page 281 before my eyes a good part of the evening while listening to the speakers, and I have been wondering why the question of efficiency of various steam generators is not reflected in the right hand column in closer proportion to the amount of coal than is shown, considering the fact of various efficiencies. We all know that the efficiency in burning coal depends largely upon the character of the steam generator or furnace to secure complete combustion, as was said by Mr. Bement. Now according to this table, it would seem that the coal consumers in flats and for domestic use are more efficient than any other type of apparatus, if we take into consideration the density of smoke made to the amount of coal burned. This seems hardly reasonable.

W. F. M. Goss, M. W. S. E.: After a careful reading of the paper, I am convinced that there is nothing improbable in the conclusions presented. I am a little surprised at the comparatively small amount of smoke which he credits to domestic fires, for I recall that in a study of this problem involving certain of the manufacturing cities of England, a very large percentage of all the smoke was credited to such fires. The smoke from the stack of a manufacturing industry constitutes a visible source of atmospheric pollution, but it may not be more serious in its general effect upon the atmosphere of a given locality than the sum total of that which is sent forth in smaller streams from a large number of domestic fires. From this point of view, the author's estimate of 6.5% of the total smoke of Chicago as coming from domestic fires seems small, but, as I have said, there is nothing in his analysis of facts which would justify me in questioning the truth of his conclusions. I am interested also in the comparatively small percentage of total smoke (18.5%) which is chargeable to the railroads. This value is, I am sure, smaller than most people have believed.

I want to add, that this study of the source of smoke in the city of Chicago, which is presented by Mr. Bird, deals with a subject of highest importance, since it should constitute an essential first step in all systematic work that may have for its purpose the elimination of smoke in this city. To my mind, therefore, the paper should be accepted as a most important contribution to technical literature.

George N. Prentiss (Chemist, C. M. & St. P. Ry.): Near the end of the discussion of the paper before your Society on February 15th, the presiding officer suggested that anyone who had anything further to say should submit it in a written communication.

As Mr. Bement asked for certain data regarding the amount of matter ejected from locomotive stacks, I wish to submit the following abstracted from Bulletin No. 402 of the U. S. Geological Survey, by W. F. M. Goss:

Of the 90,000,000 tons of fuel burned by locomotives in the United States during 1906, 8,640,000 tons were lost through cinders and sparks. This includes both the *cinders collecting in the front ends* as well as the sparks ejected from the stack, and amounts to 9.6% of the fuel fired. Eighteen tests were made, using two kinds of coal with the following results as to front end cinders and sparks ejected from stacks:

	Front End Cinders. Per Cent.	Stack Cinders. Per Cent.
No. 1	9.91	1.38
No. 2	9.92	1.43
No. 3	6.85	1.39
No. 4	4.09	2.37
No. 5	7.73	1.68
No. 6	20.40	2.20
No. 7	6.18	1.80
No. 8	5.39	1.30
No. 9	5.46	1.95
No. 10	5.46	1.23
No. 11	4.11	2.28
No. 12	1.75	1.88
No. 13	18.87	4.48
No. 14	16.79	5.95
No. 15	14.56	2.64

No. 16	9.24	2.61
No. 17	3.28	1.60
No. 18	3.35	1.51
Average of 18 tests	8.52	2.20

In Bulletin No. 363 of the U. S. Geological Survey describing tests made by the Pennsylvania Railroad and reported by Dr. Goss, the following results were obtained. Lloydell coal was used, which is described as "disintegrating rapidly in the fire-box, causing large quantities of cinders and sparks to be discharged."

	Sparks Through Stack. Per Cent.
No. 1	2.18
No. 2	1.32
No. 3	3.41
No. 4	8.31
No. 5	6.79
Average	4.40

This fall during a test made of Montana coal, a sub-bituminous, or black lignite, the character of which is such as to "throw fire" to so great an extent that its use as a fuel for locomotives is considered a difficult problem, the following result was obtained:

The train consisted of 62 empty stock cars, a dynamometer car, and a caboose, 1,050 tons. The run was 220 miles, with approximately a 0.4% grade. The speed averaged 24 miles per hour, 45,245 pounds of coal were consumed and 2.89% were ejected through the stack. The smoke was about No. 2 on a Ringelmann chart.

In view of these data, and considering the fact that both the Lloydell and the Montana coals are such as to throw more sparks out of the stack than the average coal consumed around Chicago, it appears to me that the assumption that 10% of the coal burned in Chicago in locomotives is ejected through the stack is without valid foundation, and should be placed at not above 2.5% or 3.00%.

CLOSURE.

The Author: The correctness of the figures showing the annual consumption of coal by the railroads in Chicago has been questioned by Mr. C. A. Seley, Mechanical Engineer, Rock Island Lines. He states that it is difficult to closely get at the coal consumption of a railroad terminal. Although this is true, I have great confidence in the figure given: 1,850,000 tons annual consumption. This figure was obtained in reply to letters that were sent out to each of the railroad companies operating in Chicago asking for their best estimate. As all of the coal put on locomotive tanks in Chicago is not burned within the city limits, figures showing the total coal burned by locomotives within the city limits must necessarily be estimates. The manner in which these estimates were obtained, however, warrants considerable confidence in them. The paper shows that locomotives burn 18½% of the total soft coal used in the city. This is favorable to the railroads as far as their proportion of smoke is concerned. In Bulletin No. 402, issued by the U. S. Geological Survey, "The Utilization of Fuel in Locomotive Practice," by W. F. M. Goss, it is stated that "the locomotives in service on the railroads of this country consume more than one-fifth of the total coal produced in the United States." One would expect that this proportion would be maintained in a large city as over the entire country. If it had been assumed that the railroads burned 20% of the total coal, or 2,000,000 tons annually in Chicago, the total proportion of smoke made by the railroads would be still higher.

Mr. H. T. Bentley, Assistant Superintendent of Motive Power, Chicago & Northwestern Ry., raises the question as to whether a stack of say 5 ft. in diameter would emit a larger volume of smoke than a locomotive stack of 15, 16, or 17 in. in diameter, and whether Ringelmann chart readings would give the proper density of smoke in both cases. Again all the arguments are in the locomotive's favor. Stacks of different diameters, when the velocities of discharge are the same, would of course give out volumes of smoke in direct proportion to their areas. However, the stack gases are discharged from a locomotive at a velocity of from 60 to 100 ft. per second, and from the stack of a stationary plant at a velocity of less than 25 ft. per second. In the investigation outlined in the paper, volumes of smoke are only gotten at by referring to the amount of coal burned and to the density of the smoke. The only way that the diameter of the stack affects the problem is in the effect on the Ringelmann chart reading, and this is in favor of the locomotive, because a column of smoke 18 in. in diameter must necessarily appear less dense to the eye than a column of the same smoke 5 ft. in diameter.

Mr. J. F. DeVoy, Assistant Superintendent of Motive Power, Chicago, Milwaukee & St. Paul Railway, has questioned the propriety of using the Ringelmann system in connection with locomotive practice. He has gone so far as to quote from the proceedings of the A. S. M. E. in an effort to show this. The Ringelmann system has been used for years in judging smoke from locomotive stacks. Many cases where this has been done can be cited. For instance, Bulletin 363, U. S. Geological Survey, "Comparative Tests of Run of Mine and Briquetted Coal on Locomotives," by W. F. M. Goss, describes the use of the Ringelmann charts in judging smoke from the locomotives under test. Many photographs and charts are shown in this bulletin, using this system. In the tests made on steam locomotives by the Geological Survey at the St. Louis Fair, the Ringelmann system was used. A more recent instance of the use of this scheme of measuring smoke is found in the reports of the trials of a locomotive mechanical stoker invented by Mr. D. F. Crawford, General Superintendent of Motive Power of the Pennsylvania Lines West of Pittsburg. In the *Railway Age Gazette* of June 10, 1910, a description of the Crawford stoker is given and it is stated that the smoke observations were made by means of the Ringelmann charts. There is certainly no lack of precedent for the use of this method of judging locomotive smoke. Mr. DeVoy also speaks of the inability of the average man to distinguish colors, and refers to certain tests in his own experience. The Ringelmann system does not deal with color, it only deals with density. The smoke may be any color, not necessarily black. A Ringelmann chart, to my notion, could be made with red or blue ink as well as with black ink.

No claim is made that the men in the Smoke Department are any more infallible than the average. Of course there may be differences of opinion in the minds of different men as to the density of smoke. However, it has been my experience that different men read smoke very uniformly when using the Ringelmann chart. I have made a great many tests, having more than one man watching the same stack at the same time, and their reports have been surprisingly uniform. I have often been amazed when comparing such reports to find how closely two men who are thoroughly familiar with the Ringelmann system, will record smoke observations.

Mr. Seley brought up the question that the proximity of Lake Michigan to the Illinois Central Railroad right of way might have affected the readings made on locomotives using these tracks. An examination of the paper shows that most of the observations made on the Illinois Central Railroad right of way were made at points where the lake could not possibly have been a background against which the smoke was read. A good many of the readings were taken at Randolph st., Van Buren st., Twelfth st., and at points south of Fifty-first st. At all these points the lake is not visible. The real reason why locomotives using the Illinois Central Railroad right of way present the best record is because of the hammering that they have had from the Smoke Department, the newspapers and the public. The railroads using the city's front yard have been attacked more vigorously in the anti-smoke campaign than the other railroads, and this has resulted in these roads trying harder to stop the smoke. The results in the paper show that out of the five cleanest railroads in Chicago, three use the Illinois Central right of way. These are the Wisconsin Central, Illinois Central, and Michigan Central.

Mr. Seley also said that railway locomotives are only in the city a limited number of hours each day, and that while they are in the city limits they are out of commission and smokeless during a good portion of the time. And further, that locomotives are never worked continuously at capacity for great lengths of time as are stationary plants, and yet the smoke records of locomotives when at work are compared with stationary plants in continuous operation. He says, "The smoke density of a locomotive which is in service in the city one-half hour out of the 24, has the same record as if it were operating continuously." Mr. Seley seems to have missed the point of the whole investigation. A pound of coal makes about the same volume of stack gases, no matter where or how it is burned. We have the total pounds of coal burned by the locomotives in the city; we have figures that show the average density of the stack gases, and it is a simple matter to compute the total volume of smoke made by the locomotives. The results are based on the quantity of soft coal burned and on the average density of the smoke, and do not depend upon the number of hours in a day that a locomotive or stationary plant is in use, or upon the capacity at which the plant is operated.

The statement that the sparks and cinders discharged from locomotive stacks amount to 10% of the coal burned, has been questioned. This does not in any way affect the division of the total smoke of Chicago amongst the various producers, and was included in the paper only to illustrate the objectionable qualities of locomotive smoke.

Modern steam locomotives use the self-cleaning front end, that is, they are designed so that all of the sparks and cinders that are produced will be discharged from the stack and none allowed to accumulate in the front end of the locomotive. Therefore all sparks and cinders produced are discharged into the air and dropped upon the city. The figure of 10% was obtained from Bulletin 402, U. S. Geological Survey, "The Utilization of Fuel in Locomotive Practice," by W. F. M. Goss. On page 18 a table is given which shows that out of 90,000,000 tons of coal used annually by the railroads of America, there is lost through cinders and sparks 8,640,000 tons, or 9.6%. 10% was used as an even number.

Again, on page 17 of this bulletin, in the general summary, the spark loss is given as 3% in the front end, and 9% in the form of cinders passes out of the stack, or a total of 12%. From this it would seem, as a general proposition, that the figure of 10% is conservative.

In the discussion, considerable was said about electrification but this was not the subject of the paper. The author's remarks about electrification were not even put in the conclusions of the paper. The paper merely stated incidentally that electrification offered the only final and satisfactory solution of the smoke problem. One of the chief objects of the paper was to present some facts to the engineering public which it was believed had an important bearing upon the smoke problem in Chicago. The discussion has brought out no real criticism of the facts but has shown that at least some of the railroad men do not wish to discuss the facts but rather to confuse matters by talking in vague general terms of the impossibilities involved in electrification. All that the warmest advocates of such a solution of the problem can ask, is a frank and complete study of the questions involved and an effective search made for the real facts. This paper presents an investigation of some of the factors in the problem. It is hoped that the railway interests will take a broad view of the subject and will show a willingness to further investigate and to meet the question fairly and squarely.

THE PUBLIC AND THE PUBLIC SERVICE CORPORATION.

By

John M. Ewen, M. W. S. E.

A. Bement, M. W. S. E.

Presented February 1, 1911.

The relation between the public-utility corporation and its customer, the public, is necessarily different from that between producer and consumer in general commercial transactions. In the past, however, an effort has been made to deal with the problem in the same manner that usual commercial transactions are handled. This practice has been the cause of much friction and confusion, resulting in injustice and hardship to both parties. These facts have come to be realized in a gradually increasing measure, but thus far probably no adequate method for the solution of this difficult problem, in its various aspects, has been proposed. It is the purpose of this paper to present a plan which the authors feel to be a proper and logical one for the treatment of this complicated and difficult matter, which consists essentially in the more complete development of the commission plan of adjustment and control.

In the past, it has been the disposition of the average citizen to feel that competition in public utilities is desirable. It is not strange that this is so, as he has found by experience with those purchases which contribute so largely to household and business operation, that competition is beneficial to him, and it is usually difficult to realize that conditions controlling the relation between buyer and seller are quite different when public utilities are concerned. Experience has demonstrated that competition between public-utility corporations has, in most instances, resulted in an increased cost of service to the consumer. This is natural, because if two gas or water companies are in competition, it necessarily follows that they will each have pipes for the supply of their commodity in every street of the territory served. Thus, we have two sets of equipment supplying customers on the same street, when one would have answered. While temporarily a customer may, under some circumstances, reap benefit from such competition, eventually he must pay for the duplication of service, because rates eventually cover the cost of duplication. This is true, notwithstanding the fact that in some instances under present conditions, competition between public-service corporations has, in a measure, been beneficial. But such competition is an economic error that should never be permitted, because there are other methods for the protection of the public which may readily be made available.

If we may concede that it is an economic waste to burden the community with a duplication of service, for the purpose of controlling a corporation through competition, and if we shall decide that competition is no longer desirable, it necessarily means that the public-service corporation shall be granted exclusive rights, or, in other words, be given what is generally understood as a monopoly.

The suggestion that a corporation be given a monopoly, does not appeal favorably to the public. We are, however, confronted with the fact that, notwithstanding the possible disposition of a public-service corporation to take advantage of its customers or the public, it is nevertheless necessary that it be assured a monopoly as one of the means by which the best or most economical service shall be rendered. This being true, it is necessary that the authority under which the corporation may operate shall properly define its duties and privileges, also that problems affecting the detail relations of one with the other shall be dealt with adequately, as they arise.

If a monopoly be granted a corporation, the effects incident to competition and the uncertainty of the future are eliminated. This being true, it should follow that a corporation would not feel the necessity of accumulating profits, which might be necessary under other conditions. This would tend toward service being sold at cost, which, of course, includes fixed charges, sinking fund, insurance, taxes, interest, dividends, etc., having in mind that dividends and interest are just as much cost, as is labor or fuel. But there is a danger in service being sold for actual cost, because this would remove the great incentive for progress,—that of making money,—or, in other words, realizing a profit on the business conducted, which, within certain limits, is desirable from the standpoint of the good of the public.

Thus far the problem has been dealt with from the standpoint of regulation of public service corporations by the community, but the public's obligation to these corporations has not been considered. Thus, it is felt that the necessity of the time is for adjustment of the relations of one to the other, with a full realization of the obligation of each.

As a solution of the problem, the establishment of suitable commissions as a means for handling these problems is suggested. It certainly will be conceded by those who have given the matter thought, that the general problem is altogether too large and complicated to be effectively dealt with by means now at hand. But a suitable commission of experts possessing proper authority and devoting a requisite amount of time to the problem, should insure an adequate solution, which would enable our legislators to act with a full understanding of the requirements of the situation. It is the purpose of this paper to suggest the establishment of such commissions. While the idea of the commission plan is by no means new, it is nevertheless felt that the suggestion that the rights and responsibilities of each side be given due consideration, is unique. The marked success of the work of the Board of Supervising Engineers, having in charge certain traction problems, gives weight to the authors' suggestion.

It is not proposed that a single commission be burdened with the problems of all public utilities, but that one commission be established for each character of service, because the questions which present themselves, as well as those which will necessarily arise, will require the attention of a board of specialists thoroughly familiar with the service.

Aside from the matter of determining and arranging for the more important features of franchise requirements, many problems of detail affecting the comfort and welfare of the public, as well as the success of the service, present themselves. While these are many and varied, their general character may be illustrated by a single example,—that of ventilation of surface and elevated railway cars. We have learned, especially within recent years, that wholesome air is not a matter which concerns alone the health of the individual, but is of great ecnomic significance to the community. Proper ventilation has not, however, been analyzed or considered in its various phases, with relation to the good of the individual, cost to the railway company, or the desirable amount of its supply. As a matter of fact, the solution of the problem is not simple. When those people who realize the necessity for clean and wholesome air in cars, complain when it is not supplied, they are actually confronted with the fact that a majority of the people do not want ventilation and that the railway management receives many more complaints from people who do not want it, than from those who object to foul air. Problems of this character could be solved by a commission as proposed and remedies better effected under its direction than in any other way.

In general, it is felt that the suggested commission, as briefly outlined above, is a logical solution for these great public questions, which seemed to require the attention of experts competent to analyze the problems involved.

Discussion.

President Chamberlain: We have before us tonight a paper on a topic which is of vital interest not only to the people of Chicago and to the people of this state, but to this nation generally. The question as to the proper attitude of the public and of the governments—both the local government and the state government—toward the public-service corporation, is one which is attracting considerable attention at the present time.

Charles V. Weston, M. W. S. E.: The idea of supervision of public utilities by commission has been steadily gaining ground, and in some instances where it has been adopted the system seems to work very well. No one can reasonably object to supervision pure and simple by commission, but there is a fundamental difference between supervision and administration.

When the Government goes into the business of governmental administration of public utilities it might as well go into governmental ownership, because governmental administration is only governmental control without governmental responsibility.

I think that every reasonable man is willing to accept governmental supervision which is empowered to see that securities are issued in accordance with the law, and to see that there is no further watering of stocks and to exercise authority in respect to the giving of proper and adequate service.

In some instances where commission form of regulation of public utilities has been adopted, the powers of the commission are so extensive as to usurp the functions, not only of operating officers but also those of the directorates of the corporations. I have in mind the City of New York, which is now suffering from a commission possessing excessive powers. The best example of supervision by commission which has resulted in the greatest good to the commonwealth may be found in Massachusetts. There the powers given by the legislative laws are limited and are administered in a reasonable way.

I think it may be accepted that the commission form of regulation has come to stay and that it will be gradually adopted by the commonwealths of this country until that method of regulation will become quite universal. It would seem, however, that before the commission form is adopted by any community, all other conditions in respect to the status of public utilities should be brought into harmony with the principles of commission regulation. For instance: Public-service undertakings should be operated as legalized and regulated monopolies. The capitalization of such enterprises should be limited to the legitimate cost of the operative enterprise, plus subsequent expenditures for betterment and additions to the plant. The laws under which such public-service utilities are permitted to operate should insure the integrity of the investment by regulating the compensation to be paid for the service to that amount which will return to the corporation all of the cost of rendering the service, up-keep of the property, suitable sinking funds, plus a reasonable return on the capital investment. With all these provisions accepted and a fair contract having been entered into between the service companies and the people, the logical method of regulation would be by properly constituted commissions absolutely removed from political influence.

Referring to the situation in Chicago. It seems to me that we are rapidly approaching the time when the people of this city must face the question of readjusting the public-service business, especially its transportation, along lines which will harmonize with the suggestions that I have made, and it seems to me that the whole question of commission regulation is inseparably bound up with the readjustment of the relation between the people and public-service companies.

In my judgment any effort to bring about commission regulation of the public-service affairs of this city, before the whole question of readjusting these affairs on the basis of legalized and properly-regulated monopoly is undertaken, will be premature and tend to complicate the problem rather than to solve it.

President Chamberlain: I will call on Mr. Larned, Gen'l Supt. of the Chicago Telephone Company, to tell us what he thinks of this matter of governing corporations by commission.

S. J. Larned: It seems to me that the problem as to whether or not there should be regulation and control of the public utilities is hardly an open question. There is regulation and control now in most cases. The question is, by whom shall this authority be exercised? If public utilities are not regulated by special commissions, they are regulated by legislative bodies. The mere fact that they have to go to a legislative body for the right to do business opens up the whole question of regulation by that legislative body. In fact, many of them are not only publicly regulated but their rates are also controlled by competition. The theory, of course, is that the public regulation is to take the place of competition. As a matter of fact, in many instances we have both. If there is to be regulation it would seem that there is little question as to the advisability of having that power exercised by bodies of specialists—of experts. A continuing body of that character is able to give a fitting study to the questions. Corresponding bodies in different communities, different states, are struggling with the same problems, and a special commission is able to avail itself of the vast fund of information secured by these commissions. They are governed and controlled very largely by decisions of other commissions and of courts on the questions at issue. A legislative body, on the other hand, is not apt to take into consideration other studies of the same problem, other court decisions. They are very much in the position of the literary gentleman who did not read books but wrote them. They may say they do not obey laws; they make them. Court decisions on questions at issue are not apt to be given the same weight by them as is given by a body devoting itself to such a study of the question. The temptation of the legislative body in controlling corporations is to deal with the question from the point of view of political expediency. The temptation is almost irresistible, and that generally means that in their hands rate regulation and rate reduction are synonymous terms. With rate regulation existing or inevitable, it seems to me that regulation by a body of experts who know what they are dealing with, is very much to be desired.

President Chamberlain: I think Mr. Wray, Chief Engineer of the Chicago Telephone Company, is here. We shall be glad to hear from him.

J. G. Wray, M. W. S. E.: I did not expect to be here tonight, and, therefore, had not prepared a discussion of this paper, so my remarks will be very impromptu. I have in mind a function of such a commission which has not been referred to, either in the paper or in the discussion thus far. This application of the commission idea was brought out in a meeting at the Chicago City Club, which I attended earlier this evening. It was suggested that such a commission should correlate the work of the various public-service corporations and of the city in respect to their use of the streets, so as to make for the greatest economy in construction and operation. It would seem as though the commission idea, if adopted, might properly be made to cover this phase of the subject.

President Chamberlain: Mr. Wray has brought out an important thought in connection with the handling of public-service corporations. Any of you gentlemen who have had anything to do with working in the streets of the downtown district, know that each corporation puts in its underground work wherever it can find a place for it. Then the next corporation comes along, and if in the first excavation something is found in the way, another location has to be selected. It is a very expensive proposition to attempt to lay conduit in the downtown streets at the present time, as the engineers connected with either the city or any of the public-service corporations can testify.

Another important point was brought up by Mr. Larned, and it was very clearly, I think, given by Mr. Sunny, of the Chicago Telephone Company; that is, it is unfair to a corporation to attempt to regulate it by a public authority of any kind and at the same time compel it to remain in competition with other corporations. I think probably most of you have seen Mr. Sunny's statement in the paper, in which he protested against the action of the city authorities—and I think justly—compelling the corporation of which he is president to submit to regulation by the city authorities and at the same time compelling them to remain in competition with another line of the same character.

A. S. Hibbard (Gen'l Mgr. Chicago Telephone Co.): Every thinking man who has watched the development of public utilities during the past ten years, agrees with the proposal that in the interest of the consumers and the community in general such utilities should be monopolies in the field in which they operate. It is generally agreed also that the reasonable regulation of such monopolies is beneficial to the consumers, the community, and ultimately to the companies supplying the service. Reasonable regulation can be accomplished only through the continued effort of a properly constituted body which will give continued observation to the affairs of the company to be regulated concerning its service, its development, the reasonableness of its rates, and the proper provision for its upkeep during its franchise term.

Experience has seemed to indicate that if these questions are to be determined by representatives of the community who are elected from time to time, the whole question becomes largely one of politics and not of scientific, reasonable regulation. In such a case, each time the matter of rate regulation arises it becomes, not a question of rate regulation but of rate reduction, as the officials in the supposed interest of the constituency they represent seem to invariably desire to reduce rates without much regard to the ultimate results,

The suggestion advanced in this paper, to the effect that commissions taking part in the regulation of public utilities should be composed of prominent business men and engineers, is a timely one and represents a distinct advance. It is a question, however, whether the best results may be obtained by local commissions of this character. The questions involved are by no means local. In the case of lighting, traction, or telephone companies, there are certainly statewide interests which, if considered through a state by an expert and responsible commission, would be of great advantage in the consideration or settlement of these questions in different cities and towns throughout the commonwealth. A state commission could employ the services of expert business and technical men who, by devoting their entire time to the questions involved, would render great assistance to the communities throughout the state, and their determinations would be received as representing an established authority.

The work of the commission in the state of Wisconsin during some years past has demonstrated the value of this idea. If a similar commission were established in the state of Illinois, it would soon be able to bring to bear upon the questions of public utilities throughout the state expert advice and suggestion in the interest of all the communities represented. If, on the contrary, local commissions were established, there would be one for Chicago, one for Evanston, one for Oak Park, and so on for each of the various communities throughout the state. The judgment and action of such commissions would be far from unanimous, and such an amount of conflict would be inevitable as would make it difficult for any public-service corporation serving more than one community to do its work in the best interest of all of its customers.

In the light of our experience today is it not desirable to unite in the discussion of the value of a state commission whose duty it shall be to consider the questions proposed?

President Chamberlain: We have here this evening some of the representatives of one of the corporations which we are prone to regard as a monopoly, the Commonwealth-Edison Company. I will call upon Mr. Junkersfeld to speak upon this topic.

Peter Junkersfeld, M. W. S. E.: This is a subject upon which it is rather difficult to speak impromptu. There is a point that might perhaps be emphasized in what Mr. Weston brought out in his discussion. It is recognized by some people, and most of the best thinkers of the country, that regulation by commission for at least many of the public utilities, if not all of them, is the proper thing. There is, however, a great danger for regulation to become administration without responsibility, as he has pointed out is the case today in the City of New York. There is a further danger when commissions of that kind depend for their tenure of office upon political changes. It means that certain ideas and certain policies will govern for a few years, and then certain other ideas and certain other policies will govern for a few years, which necessarily results in timidity in the investors in those securities. Timidity in those investors means that they will require a higher return for their money. Of course, in the end it comes out of the public that uses the commodity.

Commissions, however, such as exist in Massachusetts and notably in Wisconsin, that are reasonably continuous bodies and that exercise their duties fairly and justly in any case under question, when brought to their attention, are just as anxious to raise rates, if necessary, as they are to lower them, and have done so in a number of cases. Such commissions add not only to the value of the security and in that respect help the stockholders and bondholders, but also aid very greatly the public users of that commodity. The reason for this is that confidence means more capital and lower interest, a more stable business, and as a result the commodity or service can be sold at lower rates.

D. W. Roper, M. W. S. E.: The subject of the correlating work in streets is one to which a little might be added. In Chicago the work of getting all of the public utilities as well as the city utilities in the underground space available, is especially difficult because of the limited depth at which they must all work. The sewers are naturally the deepest of all of the underground utilities and in the city of Chicago they are, in the downtown district, only some six or eight feet deep. That means that all of the other utilities—the water pipes, gas pipes, and the conduits—must be above, and they must be deeper than thirty inches or something of that sort; so that, at all the important intersections in the downtown district there is a remarkable congestion. In other cities that have a little more elevation above the lake or river or other body of water adjacent to them, the sewers are deeper, which makes the whole problem much simpler, and that is one of the points that must be considered in Chicago.

C. D. Hill, M. W. S. E.: There are two or three aspects of the discussion this evening that appeal to me. One of them is this getting together on engineering lines of construction. That is outside of the subject of the paper of the evening, but it is implied. Having had charge of construction of sewers of the city for the last ten years, I have had some experiences that were painful to the corporations. In many cases we have built sewers and in making excavations we were obliged to tear up electrical conduits that had been placed wanderingly across the street in a diagonal manner or something of that sort, and having the right of way we went ahead and built the sewer and the corporation had to remove their conduit and rebuild it afterwards. Some of that could have been avoided if there had been a little get-together in advance. I have preached the get-together idea to the gentlemen representing the corporations and there have been some results, so that now we notify the corporations when we are going to build sewers and where we intend to build them; the telephone company, in particular, notify us where they are going to lay conduits and ask whether we are going to lay sewers there or not.

I do not know whether the corporations treat each other as courteously or not. I understand their idea is to put in their conduit wherever they can and let the second company move the conduit at the second company's expense. We do not pay the company for moving the conduit, so it is a different proposition.

As a practical, economic matter, it is very important that we should all get together and that there should be some bureau, some commission, some body of men that would be cognizant of what we are going to do.. Each of these corporations plans fifteen or twenty years ahead what it is going to do. Possibly they know what the other corporations are going to do. There is a practical field there and I want to emphasize that very strongly; if there is a commission to consider these things there should not be a number of commissions. There should be one commission for that very purpose of getting together for the community of knowledge that would result from it.

The other feature of the discussion is more political. It is more of a social and economic question, and that is the general proposition of governmental regulation. The paper of the evening devotes itself at some length to discussing fundamental questions that we cannot dispute, and which it seems to me would be a waste of time to consider,—the question as to whether or not there should be competition between public corporations using public streets, serving the public. There should not be any competition. The fact that corporations use the public streets absolutely results in regulation to some extent. It is inevitable. The only question is, what sort or what extent of regulation should we have? That regulation will depend upon the character of the government. If we have a corrupt government, we will have corrupt regulation, together with uneconomical construction and development of utilities, and some one has to pay the bill.

I do not know anything about the commission in New York City, but doubtless that commission is run just as fairly, just as honestly, just as reasonably, and just as efficiently as is the rest of the government of New York City. If we have a commission in Chicago, appointed by the city government, it will be just as honest, just as efficient and just as reasonable as is the government of the city of Chicago. It is for the people to say what they want; they have to pay the bill; they have to pay their taxes, and they have to pay telephone rates. If the government is corrupt, the corporation can "buy" the government or the government can blackmail the corporation. The people pay the bill. If we have a decent, honest, reasonable government, we will have decent, reasonable, honorable regulation from that government. If we have the right sort of government and a commission appointed by that government, the commission will be a commission of experts, and if the people in Chicago will maintain year after year, and administration after administration, a good form of government, that commission will continue. It will not always consist of the same persons, but there will be the same spirit, the same methods, the same rules, the same principles underlying the whole thing, and we will have good regulation.

It seems to me the only question is whether we will have one state commission for the state of Illinois, or whether we will have, say, two commissions, one for the state outside of some district considered the metropolitan district around Chicago, and a second commission for this metropolitan district. In Wisconsin one commission works very well, and every one speaks well of it. The corporations themselves are pleased with the results. They can issue bonds and sell them at par up there. They have fair rates. They do not have any competition. If there is a private water company in a town, the town cannot put in a competing water company. In Illinois that may not work so well, simply for the reason that we have this very large metropolitan district where there are engineering questions that are different from the rest of the state. It is somewhat inconceivable that a state commission could deal with these problems of using the limited area between street lines for the innumerable uses of the various corporations and the uses of the city. It seems to me it would be much better to have a local metropolitan commission that could handle that question as well as the other, and I see no reason why such a commission should not be effective and honest and reasonable in its operations in every way. The Board of Supervising Engineers has been criticised very slightly during the last three years for the expenditure of forty million dollars. Their work in rehabilitating all the street car lines is nearly finished; the greater part of it is done. I see no reason why such a commission should not continue. It may not consist of the same individuals, but the work should be along the same lines. A commission could take over their work, carry it on indefinitely, handle the work with the corporations, and work with the city's own departments using the streets. With a proper commission that really considered the city as coming under its supervision, and a commission that was friendly toward the city administration and a city administration that was friendly toward the commission, there is no reason why they should not all work together harmoniously and produce good results.

John Ericson, M. W. S. E.: There is one point in connection with the subject under discussion on which I have a decided opinion, and that is that the underground work, as far as the regulation of it is concerned, should be correlated under one head and one commission, because the way that work is done now is very objectionable, costly, and confusing, and the sooner that can be brought about the better I think it will be for all concerned.

J. W. Mabbs, M. W. S. E.: I take a deep interest in all matters pertaining to public utilities. The matter of a commission form of government has always appealed to me, and it seems to me that it is the line along which engineers and all good citizens of Chicago ought to work. If we had a commission form of government and a body that absolutely controlled this city in place of, for instance, the City Council that we now have, the amount of money now paid in salaries to members of our City Council, if paid to a commission of, say, ten men, would be sufficient to engage the ablest men in this country. We could then have a man at the head of each particular line, that would be an expert in that line; and utilities could be more efficiently, economically, and harmoniously handled in that way. Such a method of administration would result in, it seems to me, an ideal city and an ideal government.

Some of the speakers intimated that they think it is not fair for a commission to regulate without taking the responsibility. I agree with those speakers most emphatically, and think that the commission should regulate and should take the entire responsibility. I think the transportation of this city, the lighting, the water works, the sewerage, the gas, the telephones, and all the public utilities should be under a commission governed and regulated by a monopoly, and that monopoly should be the people of Chicago.

President Chamberlain: There seems to be a unanimous sentiment, that the commission plan is correct, but I think this idea will have to be preceded by a campaign of education; in fact, I think that the campaign has already started. There is no question that there is, or has been, a popular feeling that competition is a good thing. As stated in this paper, people get an idea that competition is a good thing because they have found that it has reduced prices in domestic affairs. I think the people are beginning to be educated along the lines of the necessity, the absolute necessity, of public-service corporations being monopolies and being properly regulated. As has been brought out this evening, one of the very important things that must be done is that a commission to look after the public utilities must be taken as far as possible out of politics. The men that constitute such a commission, as Mr. Mabbs has stated, must be men of the highest character and standing in their professions and above reproach, and there is no question that such men could be secured if some of the public moneys which are wasted on poor legislators and poor legislation were put to the proper use.

A. J. Hammond: The trend of the discussion seems to be a great interest in securing more effective administration. The problem of a commission that will govern, as suggested by Mr. Mabbs, is becoming a very interesting one to all the states. I do not know, however, that he had especial reference to the ideas brought out by the writers of this paper. The matter of a commission that will govern is really a different proposition from that of regulating public utilities by a commission. It seems to me that a great many public utilities which are naturally monopolies can only be controlled by the ideal commission.

This subject I think is a very timely one and an interesting one to bring up before this Society.

R. F. Schuchardt, M. W. S. E.: The commission form of government, which has just been mentioned and the short ballot are looked upon by students of political economy almost as panaceas for all the corrupt conditions existing in our city governments. If the commission form of government were adopted more generally, there is no doubt but that the conditions which caused Senator Frye recently to "despair of the republic" would very largely disappear. In the same way, a public utility commission is depended on to solve the many problems which have frequently been the cause of political corruption.

How effective such a commission would be depends on two things. First, the limit of powers of such a commission, as has been pointed out by Mr. Junkersfeld and some of the other speakers. If it had administrative powers without responsibility for the results,—results to stockholders and to the public,—as in New York City, the probability is that the commissioners would be at constant warfare with one or more of the corporations. Second, the kind of men that are appointed on that commission. If permanent appointments can be made and the class of men such as are on the Wisconsin Railroad Commission, for instance, will serve and stay on such a commission, there is no doubt about the beneficial results.

There is one particular advantage resulting from the appointment of such a commission, and I do not know whether the corporations or the public will be the greater gainer, that is the removal of public-service corporation questions from politics, in the way of taking from politicians who seek public honors the slogans based on some popular cry against corporations. We have had examples in this city, where the traction question was kept in politics, as has been frequently stated, in order to keep in office certain politicians. At the present time we have another illustration of the same thing.

where the attempt to reduce to a certain arbitrary price the product of one of the corporations is again being used as a war cry to help into power. The removal from politics of such questions, and the malevolent agitation in connection with them, will more than justify the appointment of a properly organized public-service commission.

Mr. Wray: I wish to add just one more thought to the discussion.

Referring to the New York Public Service Commission's powers, and to the remarks of one of the speakers this evening, who would have the public-service corporations, as well as the business of the municipality, in the hands of a commission, I would call attention to the fact that each particular line of business requires expert administration. Mr. Larned and I think we know something about running the telephone business, but we would hesitate to undertake Mr. Junkersfeld's job, although the telephone business and the electric light and power business are not so very different in some respects. We would also hesitate to undertake to operate the gas company's business or the city's water plant or the traction company. Each public-service undertaking requires a definite kind of experience and talent, and I doubt very much if the administration of those undertakings could all be successfully and economically carried on under one administrative commission. It is one thing to administer the affairs of such a corporation. It is another thing to have a certain measure of public control to see that the concerns are not mismanaged against the interests of the public or of the stockholders. Now, further than that, we have to bear in mind that public-service corporations must carry on their business in such a way as to be able to expand, and be able to expand in a healthful way, to attract additional money so that they can take care of the requirements of the community. While the economies that can be worked out from planning advantageously as to the use of streets and so on are considerable, I believe that they can be brought about in the ways indicated in the previous discussion and without running the risk of great losses due to mismanagement by administrative bodies who are not experts on the business of each corporation.

G. L. Clausen, M. W. S. E: The discussion tonight has taken a broader aspect than I expected. There are some things that I would like to call attention to. In the first place, we are here as a body of engineers belonging to the Western Society of Engineers. We have branched out in the discussion tonight in a way that, in my estimation, is a little beyond our sphere or our intention as an engineering body.

Mention has been made of a commission form of government, and the like, and it is my opinion that we, as a body of engineers, should be careful not to go beyond our limits. I do not think we are here necessarily to advocate changes, radical changes of government and political conditions as they exist, whether they be in the Union, state, or city. I think that as engineers our function is to gather facts. I believe that we will be readily received by any governing body as long as we can present the facts that the governing body is looking for.

There is no question, gentlemen, but that we are all progressive. Particularly, I think, in the city of Chicago great progress has been made in a lifetime. I am familiar with the engineering work of Chicago covering the past thirty years or more. If we will look back over the last ten or fifteen years and compare our conditions of today with those which existed in former years, we can readily see that we have made great progress, in that our city administrations realize the necessity as well as the economy of obtaining engineering facts from the best specialists or experts, regardless of political affiliation.

We are progressing, and I believe that if we, as engineers, can obtain facts and make known in the proper manner that we are able to furnish the very information that our governing body needs, no governing body will be or dare be so corrupt as to ignore such source of information because of any undue motive. Examples have been mentioned tonight. In fact, I believe that our first experience was with the Board of Supervising Engineers of our street railway system. As Mr. Hill said, very little criticism has been made and I believe very little criticism could be made. I think as engineers they have done remarkably well. They have indicated what should be done and their ideas have been carried out. If we, as engineers, can indicate in the proper manner and through the proper channels, that we are representative engineers, we should be called upon as engineers in our various capacities to form a commission,—an advisory commission. I am of the opinion, I regret to say, that in general engineers are not good administrators; they are men of facts and figures. So, if we could establish ourselves as such, and be men of facts and figures, we would get the proper recognition.

J. R. Cravath, M. W. S. E.: The last speaker intimated that we, as engineers, should confine ourselves to a narrow field and we have been inclined to do this in the past. At the same time, we must recognize that there has been within the last few years a very noticeable movement (a movement which those who attended our last annual dinner had brought to mind) for the engineer to assume the place which he properly should assume, by virtue of his special knowledge, in the general conduct of our government, whatever it may be.

The discussion of this commission regulation of public utilities is going to be perhaps of more immediate practical importance than the discussion here has indicated. At the last session of the Illinois legislature I believe at least one bill was introduced looking toward certain regulations of that kind, and I think in the present legislature at least one bill of the same kind has been introduced. It is up to us as engineers to use our influence in having put in force a way that these commissions should be constituted to have them free from political influence, and a way which will secure the competency of the men on them.

R. H. Kuss, M. W. S. E.: Granting that the office of the public-utility corporation is such as to preclude the duplication of equipment by competing corporations, if economy of service is to be considered paramount, it does not follow that it is fundamentally right to grant private corporations monopolies in the communities served. If we must have privately-owned public-service corporations there is, of course, no valid argument against the creation of regulating commissions. That the millennium is not reached by such a system is my contention as I shall try to show by bringing up a few points that need to be considered.

The regulation of public-utility corporations enjoying monopolies must be so performed that a fair return for the service, charging all of the expenses incident thereto including a reasonable return on the investment, shall accrue to the corporations; the charge to the public shall be such that the conduct of the service shall take care of such established returns and no more; any larger return to the corporations is unfair to the public. It is possible to defeat the purpose of the system by agreements between private corporations made up of stockholders common to both and the monopoly wherein the regulated corporation is charged exorbitant amounts; the real profit, which should appear in the conduct of the public-utility corporation, is simply transferred to another organization, not controlled by the commission. There is nothing uncommon in this method of circumventing the intention of regulations.

The creation of a regulating commission is subject to the same criticism as is made with respect to the competitive system, an unnecessary duplication is provided. The duplication may be less in extent than the competitive method, but it is no less a duplication on that account.

The regulating commission must be, in point of knowledge, skill, integrity, industry, shrewdness, etc., no less capable than the officials providing the service; any less efficient body becomes worse than none at all, since there is then provided a false security which leads to greater abuses against the public than the competitive system would permit.

If it is possible for a commission to render adequate service, it becomes apparent that the commissioners should be placed in positions rendering the service to the public direct. If we must accept the common conclusion that public officials, using the term in the usual sense, cannot be entrusted with responsibilities, then we must also conclude that commissioners who are only one kind of public officials, are no more capable, especially as their duties become largely advisory, and the responsibility for specific acts becomes the more clouded. What assurance have we that commissioners are to be armed with greater strength of character and ability than those who could and would be selected to serve the public where the principle of monopoly is justified under direct public operation?

The human virtues that will make a commission form of *monopoly-regulation* work out satisfactorily will also make it possible for the *monopoly-right* to be withheld and a public ownership to be substituted; the human weaknesses that would defeat public ownership of public utilities will also defeat the regulation of private monopolies acting as public-utility corporations.

CLOSURE.

The Authors: The main point which Mr. Weston develops is a most significant one, as it serves to illustrate the one-sided view so largely adopted in the consideration of this whole matter and the natural outgrowth of a feeling that municipal ownership or operation might be considered a logical remedy. If the matter had been given adequate consideration in the past, there would be less fear on the part of public-service corporations, and desire on the part of the community, for municipal ownership, or operation, than has sometimes been manifest. A comprehensive analysis of the problem indicates the necessity for highly developed and specialized operation, which may be had only through the administration of an agency having an incentive, thus insuring that the highest and best character of service will be rendered. In this age of specialized industry, the public-service corporation is an undoubted necessity.

One of the most striking features of the discussion of this paper is the frequent use of the word "regulation" by the various speakers, it being also used with reference to the public-service corporation, but nothing has been said by the various speakers about regulation of the public or of the individual who makes use of such utilities.

It would, of course, be necessary that such experts, like those of any other effective commission, be insured a proper tenure in office and be free from the disadvantages incident to the usual elective office.

The matter which Mr. Hill presents serves to illustrate, in a marked manner, some of the needs of such scheme, as suggested in the paper.

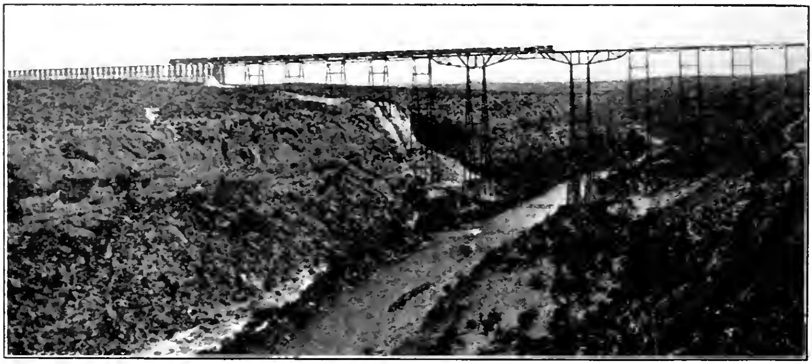
REINFORCEMENT OF PECOS VIADUCT

W. H. ALDERSON, M. W. S. E.

Presented December 14, 1910.

The Pecos viaduct in Texas was built in 1891. Before that time the main line of the Galveston, Houston & San Antonio Ry., (now part of the Southern Pacific Ry.) made a detour to the mouth of the Pecos River, a few miles below the viaduct, crossing the river on an ordinary deck structure just above high water. The old line was expensive to operate on account of heavy grades and curvature, and was also expensive to maintain for the same reasons and on account of the unstable nature of the rock in the cuts. As large masses of rock frequently fell in the cuts, it was necessary to keep the track patrolled continually.

The viaduct is 321 ft. above the river and ranks among the high bridges of the world, being for many years the highest bridge in this country. It consisted of thirty-four 35 ft. deck plate girders; one 45 ft. deck plate girder; eight 65 ft. lattice girders, with a central truss of two 85 ft. anchor arms; two 52½ ft. cantilever arms, and an 80 ft. suspended span, making a total length of 2,180 ft. All the towers were 35 ft. long. The trusses and girders are on 10 ft. centers throughout. The total amount of metal was 3,640,000 lb. All the columns except those in bents 13 to 16, supporting the cantilever trusses, consisted of four 6 in. Z-bars. The columns in bents 13 to 16 were two built channel sections laced together. All material was iron except the Z-bars in columns, which were of steel. The bracing of towers was of diagonal rods with



Pecos Viaduct—West End Taken Out and Tracks on False Work.

horizontal struts of four angles laced, forming an I-shaped section. The lateral bracing of girders and trusses was of rigid members throughout. The lateral bracing on the trusses was composed of members built of four angles, laced, making an I-shaped section of the same depth as the chords. The sway bracing on the cantilevers had diagonal rods with horizontal struts consisting of four angles.

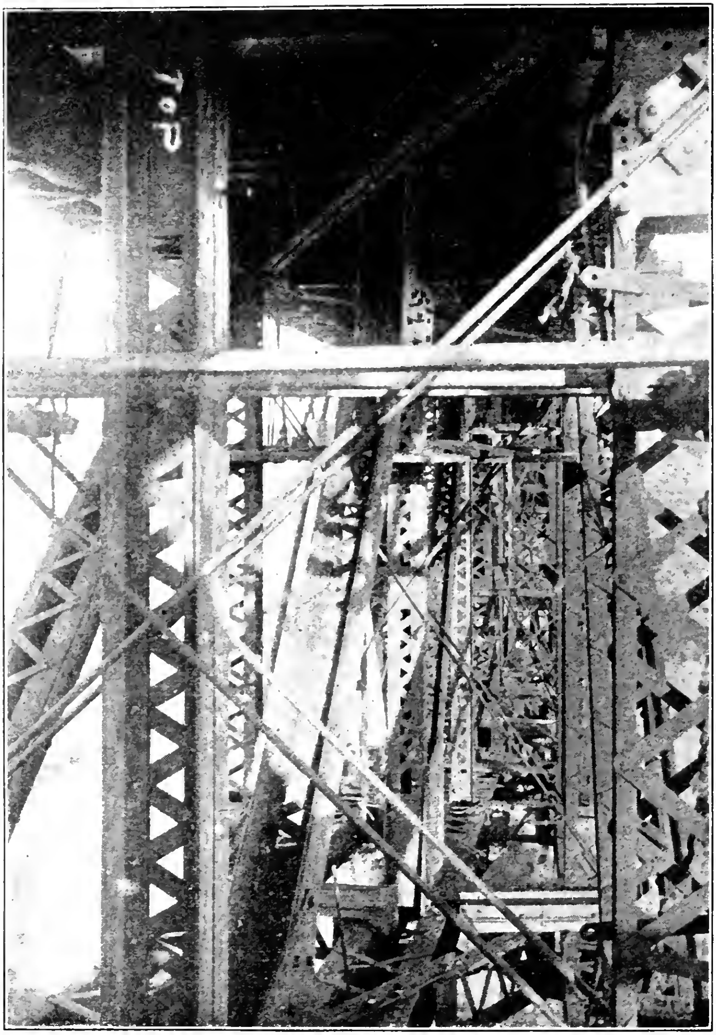
The viaduct was built by the Phoenix Bridge Company and was designed for a live load of 5,000 lb. per ft., with a concentration of 30,000 lb. The old structure was found to be in excellent condition, as it had been carefully maintained; all trains had to come to a full stop before crossing it, and the speed over it was reduced to about ten miles per hour.

For several years the lightness of this structure seriously handicapped the economical operation of the road by limiting the size of locomotives which could be used, and it was desired to reinforce the structure for the present standard loading of the Harriman Lines, which is about equivalent to Cooper's specifications E-55. It was necessary that the work should be done under traffic, and several schemes were considered for reinforcement.

For the 35 ft. girder spans it was first proposed to put in false work for about three spans from either abutment, removing these spans to either bank and there adding the necessary reinforcing steel, after which these spans could be substituted between trains for three other spans, the spans taken out reinforced and substituted for three more, and so on until all spans were reinforced, the last three being placed in the panels where the falsework was used. But when the 35 ft. spans at the ends of the anchor arms were considered, it was found impossible to get them out on account of the details at the ends of the anchor arms. The cantilever trusses required a very large amount of metal to be added, a large number of old rivets to be cut out, and new holes to be drilled. For these reasons it was decided to put in new center cantilever trusses and new 35 ft. girder spans adjacent to the anchor arms.

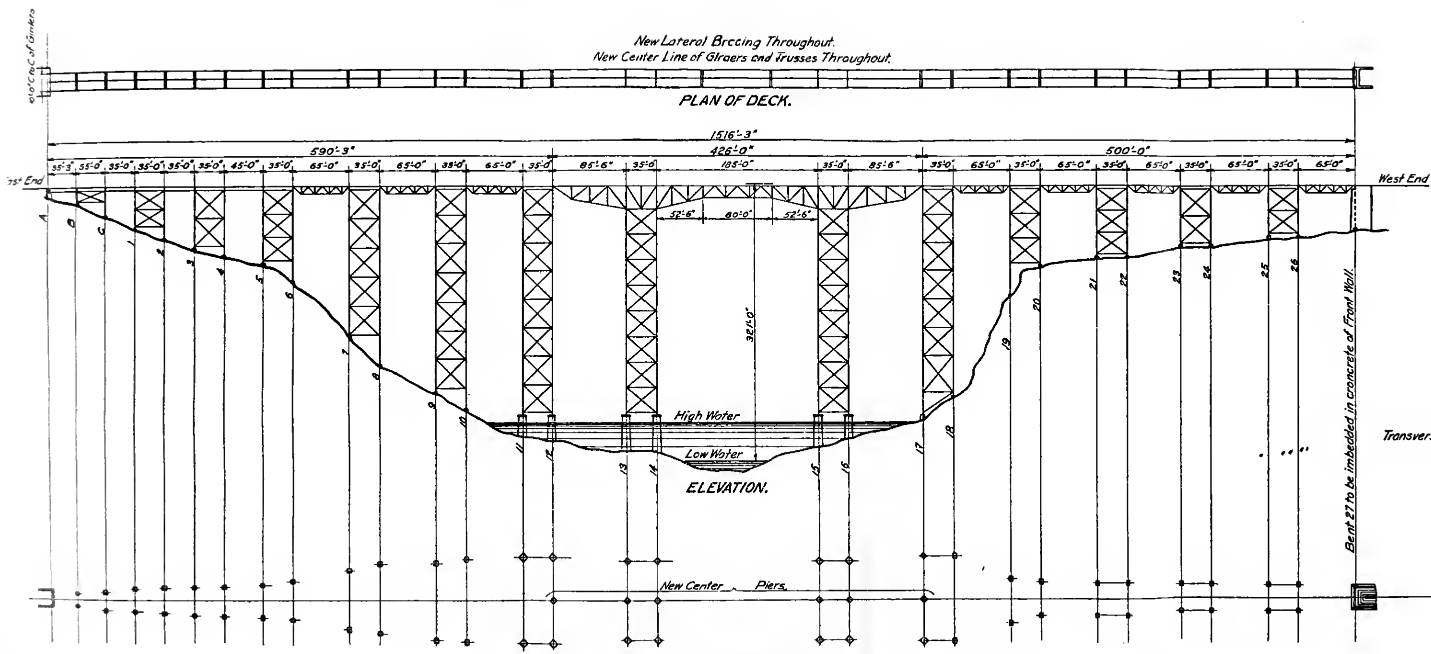
The 65 ft. lattice girders were found to require a very small amount of reinforcing—principally for strengthening the details and reinforcing the top chord for transverse tresses. Plans were made which would allow of doing this work without interfering with traffic or weakening the spans while reinforcing them.

New center girders for all of the 35 ft. spans were then considered. This required considerably more metal than for reinforcing the old spans, but did not involve the expense of removing the 35 ft. spans. It was considered undesirable to have three girders for all the 35 ft. spans and cantilever trusses, and two girders for the 65 ft. lattice girder spans, so it was decided to put in a center line of girders and trusses for the whole length of the structure, even though the 65 ft. spans could be easily reinforced. The most logical way to carry the load from the center girders to the columns was found to be by means of transverse girders at the tops of the bents, and that plan was adopted. These transverse girders were made double, each half being riveted to the face of the columns, with a diaphragm placed in the center connecting the two halves. While the existing bracing was sufficient in amount, the time and expense of cutting it to clear the center trusses and girders, as well as making connections, rendered its use impracticable, so new lateral bracing for all spans



Inside of Cantilever, Showing Some Details of New Center Truss.

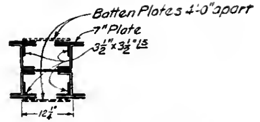
new center columns were made of two plates and four angles, or two built channel sections. They were built in halves in the shops.



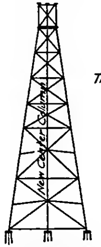
PLAN OF DECK.

ELEVATION.

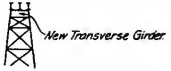
PLAN OF PIERS.


Batten Plates 4'-0" apart
7" Plate
$3\frac{1}{2}$" x $3\frac{1}{2}$" Ls
$12\frac{1}{4}$"

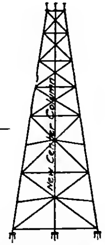
SECTION
Reinforcement for Cols. Bents 1 to 11 inclusive and Cols. Bents 18 to 26 inclusive.



Transverse Elevation of Bents 13-14-15-16.



Transverse Elevation of Bents B to 11 and 18 to 26 inclusive.



Transverse Elevation of Bents 12 and 17.

PECOS RIVER VIADUCT
G. H. & S. A. R. R.
GENERAL PLAN and ELEVATION

Notes:-
Portion of Viaduct from Bent No. 28 to Abutment 46 removed for fill. 19-35 Girder Spans and 18 Bents removed.
Steel Columns of Bents 27 and 28 encased in the new concrete Abutment.
Present Columns of Bents 12 to 17 inclusive not reinforced. These Bents reinforced by new Center Column.

was decided upon. New X-frames were used between the center and outside girders.

For the cantilever trusses the new sway braces had diagonal rods, except at the inclined posts at the ends of the anchor and cantilever arms, which had diagonals made of rigid members. These rods were in pairs and were threaded on the ends, having nuts bearing on lug angles riveted to the faces of the posts of the old trusses. This permitted the new rods to be put in place and tightened up before the old ones were removed. The posts on the center truss were slipped in between the rods, but not connected to them, so that the center and outside trusses could deflect independently.

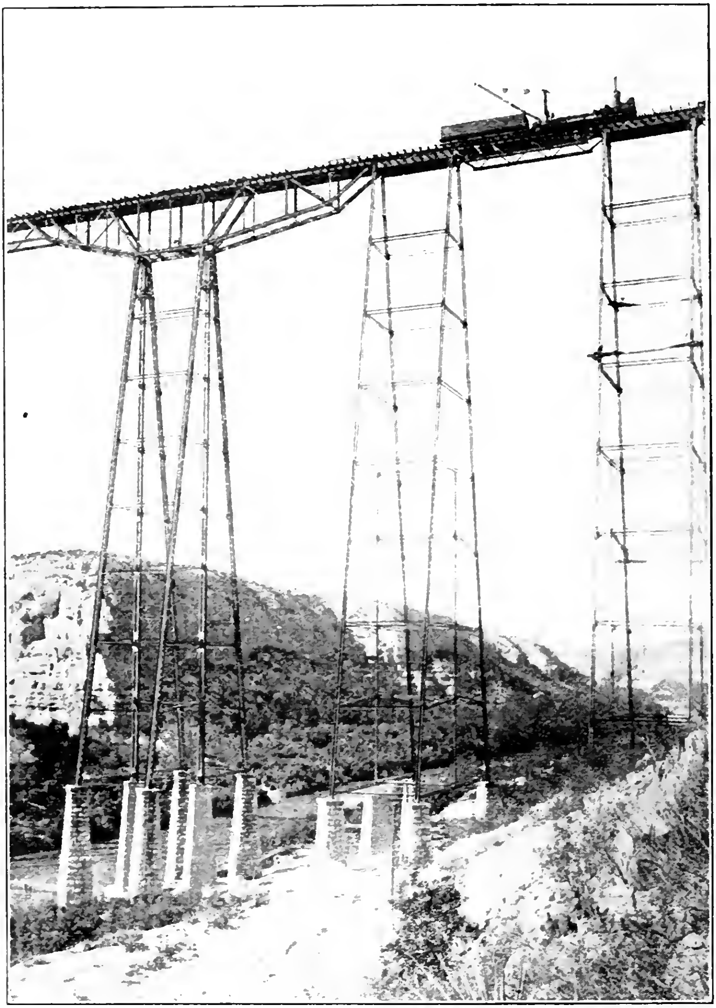
The center 35 and 45 ft. girders were made the same depths as the old outside girders. For the 65 ft. lattice spans new center plate girders were used, which were the same depth as the old spans, and were reduced to 4 ft. at the ends in order to be the same depth as the adjacent 35 ft. spans. The new cantilever and suspended-span trusses had the same outlines as the old trusses, but were made riveted instead of pin-connected.

The new center girders and trusses were designed to carry five-eighths of the load on the track, that being the proportion carried to them if the ties acted as continuous beams. The old trusses and girders were found, after careful checking, to be safe for one-quarter of the load on the track, which load would be carried to them if each half of the tie acted as a single beam. It was thought that the real action of the tie in distributing the load would be somewhere between these two assumptions.

The Z-bar columns were reinforced by adding four 3½ by 3½ in. angles placed as shown, and if this did not add sufficient section, four 7 in. plates were also added. At the horizontal struts in the lateral bracing the plate was notched around the same, and the outstanding leg of the angles was cut off. The section was made up by putting on an angle riveted to the flange of the Z-bars with its outstanding leg in the same place as the Z-bar web. Batten plates were used connecting the reinforcing angles to stiffen the columns. These plates were made long enough for three rivets and were placed 4 ft. apart. The transverse girders at the tops of the bents had connection angles riveted to the outstanding flanges of the Z-bars.

Shelf angles were provided to facilitate the erection of these girders. When the columns in bents 12 to 17, supporting the cantilever trusses, were considered, it was found that so much metal would have to be added it was practically impossible to reinforce them. These columns were found to be of sufficient section to carry the load on the outside trusses, so it was decided to add a new center column to these bents. It was found that the columns in bents 11 and 18 would have to be reinforced even if new center columns were added, so it was decided not to use them in these bents. The new center columns were made of two plates and four angles, or of two built channel sections. They were built in halves in the shops, and the lacing and batten plates were riveted on the field. This made it unnecessary to cut any of the old bracing, except the longitudinal struts on the center line of the bridge.

The highest bents had a vertical strut on the center line of the bridge for about half their height, and the old strut was inclosed by the new center columns. These new center columns were braced laterally by being connected to the old horizontal struts, but not to the diagonals. The two center columns in a tower are braced longi-



New Center Columns Supporting New Center Cantilever Trusses.

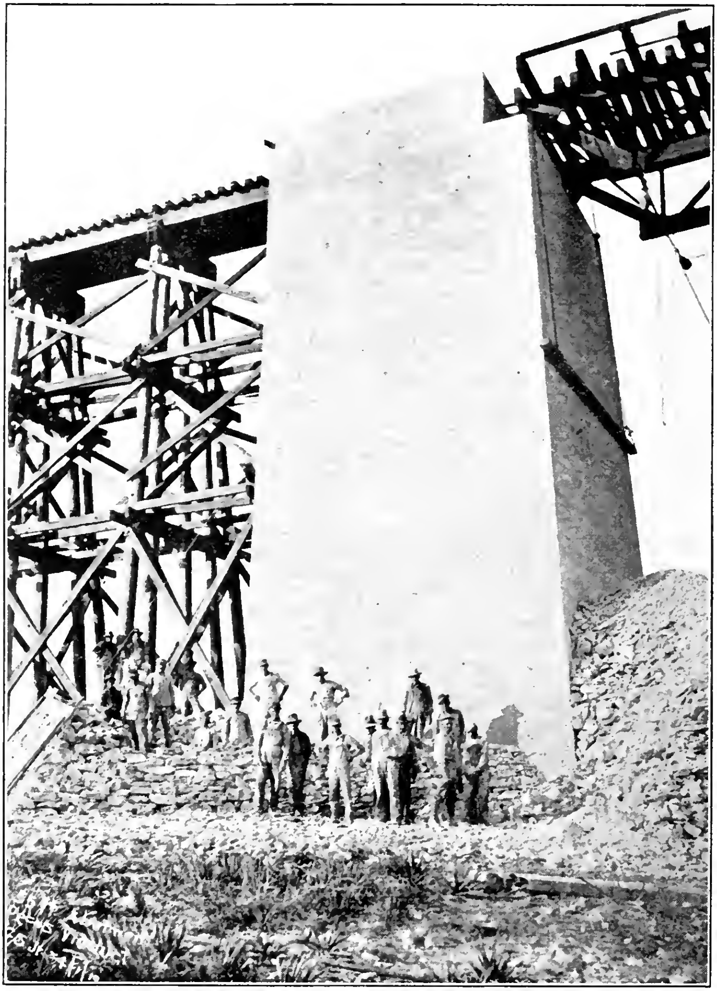
tudinally by a system similar to that of the outside inclined posts. In bents 11 and 18 the old center vertical strut was extended up the full height of the bent and connected to the center columns in bents 12 and 17 by a system of longitudinal bracing similar to that for the center columns in bents 13 to 16.

The old tower bracing consisted of diagonal rods and horizontal struts of four angles laced. Rods and struts were found to be of sufficient section to carry the wind stresses, and as they had developed no weakness under heavy traction stresses, it was considered safe to leave them in and not put in new bracing. The tops of the new center columns at the ends of the anchor arms have a short length of stub column made to telescope into the main-column section, the holes for connecting the top section being drilled in the field. This allowed a vertical adjustment of the links at the ends of the anchor arms. At the ends of the old anchor arms there was a short link pin-connected to both the truss and the column. A similar detail was used on the new truss. These links were made in halves so that the pin could be set in the end of the truss and the halves of the link slipped over it, as there was not room enough to drive the pin through both link and truss.

For supporting the center column, an A-frame or truss carrying the load to the existing piers was considered, but it was found impracticable to get a bearing on the old piers, not on account of the piers being too small, but on account of their being placed diagonally to the center line of the bridge. For this reason new center piers were decided on.

The new piers are similar in shape and size to the old ones and, like them, were made diagonal to the center line of the bridge. Their tops are 2 ft. below the tops of the old piers, which was done to allow the base of the new column to clear the old bottom strut of the bent. This base was made in halves, like the rest of the column, the two halves being connected by field rivets through the outstanding legs of the vertical angles on the wing plates.

It was decided to remove 19 spans or 665 ft. of the west end of the viaduct, which involved building a new abutment at bent No. 27, and several plans were considered. One was to inclose the posts and struts of tower 27-28 in reinforced concrete and allow the fill to spill through the tower, and in order to keep the fill away from the girder a bulkhead, or back wall, would have to be built at the top of bent 28. It was thought, however, that settlement of the fill would bring heavy stresses on the horizontal struts, and the whole plan was considered very risky and unsatisfactory. Another plan considered was to make a box of tower 27-28 by making reinforced concrete walls in the planes of bents 27-28 and the inclined surfaces of the posts between bents 27-28, the tops of these walls to carry a reinforced concrete slab for the track. These two plans were discarded in favor of a U-abutment, which was made of rather slender dimensions and would have been made a pier in the middle of the fill but for the necessity of keeping the toe of the fill away from the steel of bent 26. As finally built, this abutment was 55 ft. high and has a base about 3/10 of its height. The wing walls were 17 ft. long from the face of the back wall, and bent 27 was imbedded in the abutment. While the abutment is very tall and slender, it is considered safe as the fill is made of rock, and that part of the fill in front of and around the abutment was very carefully placed, so as to eliminate any tendency to slide.



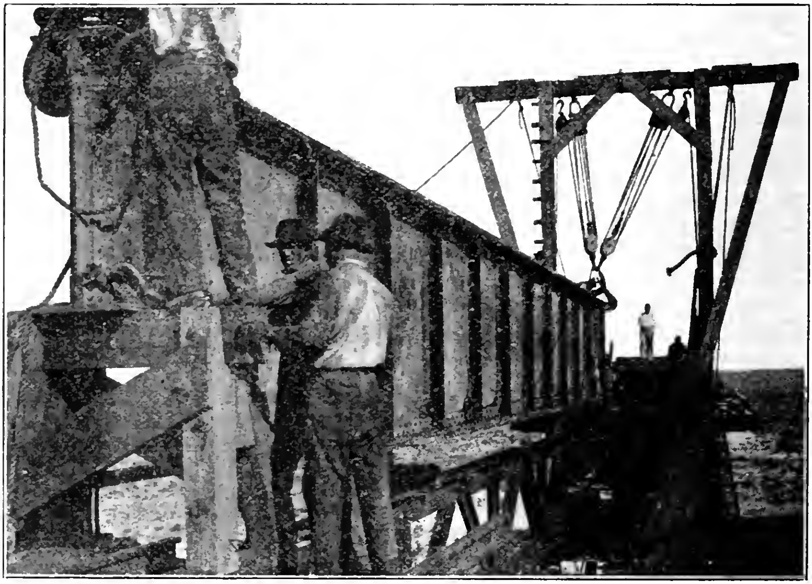
New Abutment at the West End.

In carrying out this work in the field it was desired that unnecessary chances were not to be taken in order to hasten the work; at the same time it was also desired not to delay traffic unnecessarily, and in order that the contractor for erection should be fully familiar with train movements, the railroad company stationed a telegraph operator at the bridge site.

The material as received from the shops was sorted out and stored near the east end of the bridge, some temporary side-tracks having been put in for this purpose. The contractor set up an air compressor with a 4 in. pipe leading half way across the bridge, but reduced it to a 3 in., and later to a 2 in. pipe. At the center of each tower a 2 in. pipe led vertically downward from this main, and Ts were put in at each panel point in the tower, from which a hose connection was made to the riveters and drills. A derrick car was made by mounting an engine and an ordinary boom on a flat car, the boom having a reach of 40 ft. from the front of the car and a capacity of 10 tons. The material for reinforcing the Z-bar columns was first distributed to proper bents and clamped in position. Drilling was started at the tops of the bents and progressed downward. A scaffolding was used for the drillers and riveters, which consisted of a longitudinal timber against the inclined legs of the tower. Across these, at the ends, were short timbers transverse to the bridge and against the face of the bents. At the intersection, diagonal planks were laid, forming a small platform around the column. This scaffolding was raised, when necessary, by the derrick car used for placing the steel.

The general procedure in reinforcing a column was to have a drilling gang at each column on one side of a tower, which worked downward for about one-third of the height of the high towers. The scaffolding was then raised to the top of the tower and riveting was done for the upper third; then the middle and lower thirds were finished in the same way. By having several sets of scaffolding it was possible to carry on reinforcing of several of the towers at once, drilling and riveting gangs being shifted from tower to tower as necessary. The material for center columns and transverse girders was lowered over the side by the derrick car; in the case of low towers, it was laid on the ground until a line could be dropped through the deck of the structure; the material was then carried up into its final position. In the case of high towers the material was held by one line until another could be dropped through the deck, when the material was picked up and hoisted in position as was done for the lower towers.

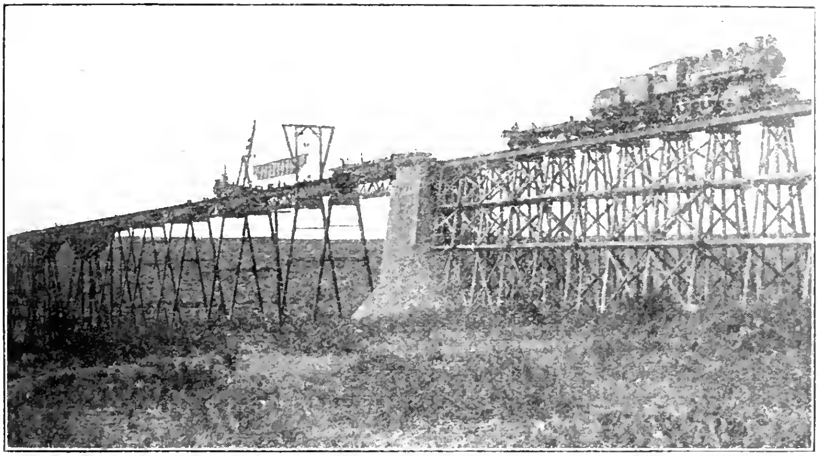
For placing the 35 ft. girders and all of the cantilever trusses except the bottom chord, it was necessary to remove the floor of the bridge. This was done for one span length at a time, and did not interfere with traffic over the bridge. The 65 ft. center girders weighed 18 tons and therefore could not be handled by the derrick car alone. By lifting one end of the girder, cribbing up just beyond the center of the span, letting that end of the span drop, cribbing up the end, and then raising and cribbing up the center a little more, these spans were gradually raised to the height of the flat car and skidded on to two cars. A gallows frame, having a set of falls leading from each upper corner, was built which could be placed on the top flanges of the old outside girders. An idler flat car, with a snubbing post on each side, was then placed between the locomotive (which was placed at the disposal of the contractor) and the two flat cars carrying the 65 ft. girder. By slacking off on one line or the other of the falls, the girder could be swung from side to side. This gallows frame was set by a derrick car, and the derrick car then moved off the structure, when the locomotive with three flat cars were moved out into position. One end of the girder was picked up by the two lines from the gallows frame which passed around a sheave at the bottom of the frame and led out horizontally to the snubbing posts on the flat-car idler. By pulling ahead with the locomotive, this end of the girder was lifted, the derrick car raising the other end, when the flat cars on which the girder was loaded were pushed out through the gallows frame by hand. A small wooden pedestal was built which now supported the end of the girder raised by the derrick car, the other end being held by the lines from the gallows frame. The derrick car then removed the ties and



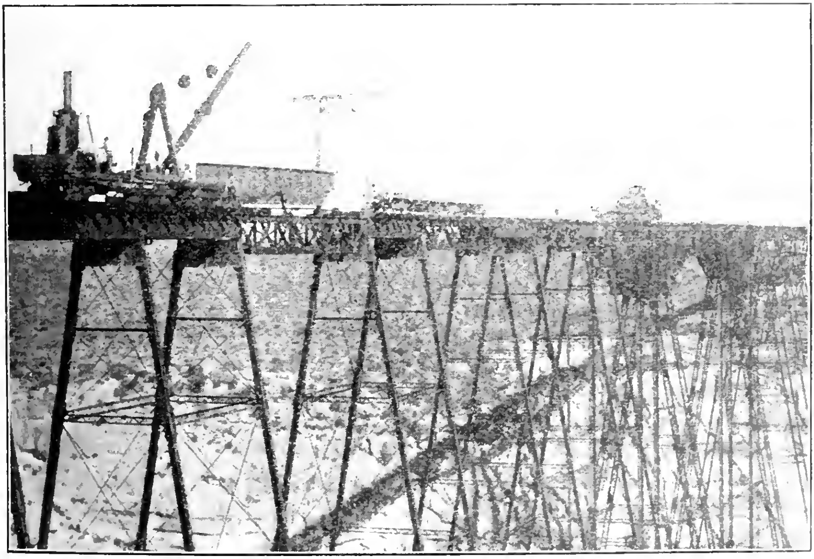
Gallows Frame and 65-foot Girder—Ready to Drop Into Place Under Center of Track.

rails from the 65 ft. span and the center girder was lowered in position from the gallows frame and derrick car, the total operation taking fourteen men about four and one-half hours.

The new cantilever trusses had the lower chord placed first, and the contractor was allowed to cut only one panel length of the

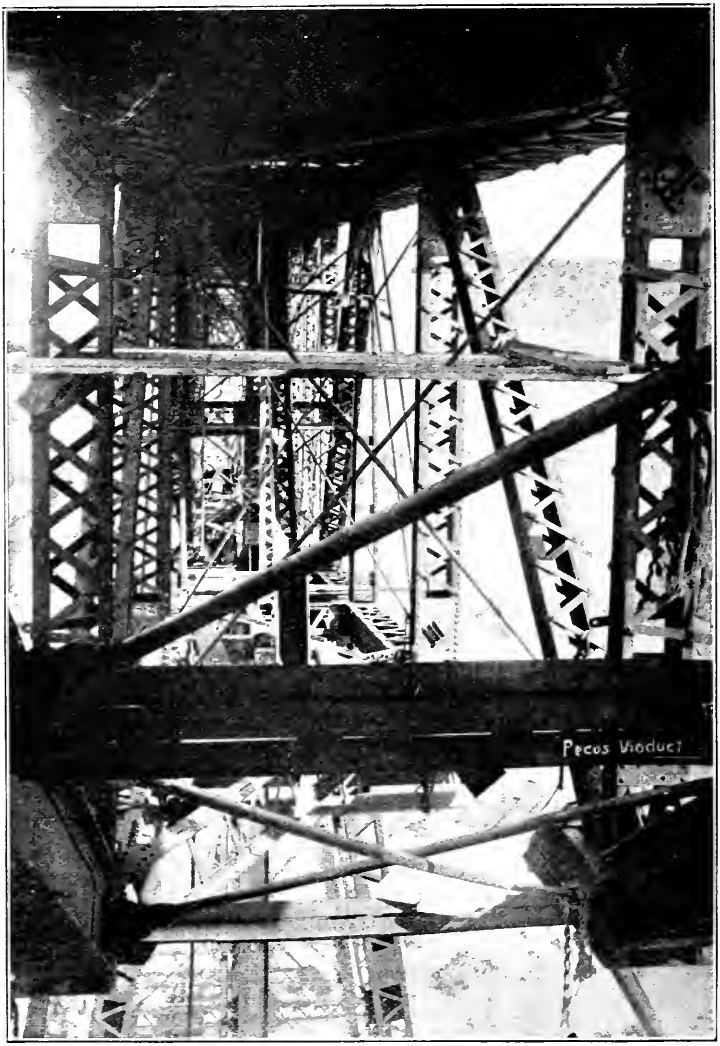


Setting 65-foot Girder—Also New Masonry Abutment at West End.



Setting 65-foot Plate Girder, with Derrick Car and Gallows Frame and Showing Transverse Girders.

lateral bracing at a time. The chord was suspended from the old structure by means of 12 in. by 12 in. beams. The web members were then placed for a few panel lengths and the upper chord lowered over them. As mentioned before, the new diagonal rods were put in place and tightened up before the old rods were removed and the new vertical posts slipped between them. In this way the canti-



Inside of Cantilever Trusses Looking Toward the Center from the End of the Anchor Arm.

lever was gradually built one member at a time, the new center trusses being supported from the old structure. Closure was finally made by wedging up the new center trusses.

The reinforcing material was fabricated by the Phoenix Bridge Company, and the erection was done by the Missouri Valley Bridge and Iron Company. The amount of reinforcing-steel added was about 2,200,000 pounds.

As a whole, the entire work was very satisfactory. Plans for reinforcement were prepared by the writer under the direction of Mr. John D. Isaacs, Consulting Engineer of the Harriman Lines. Mr. D. K. Colburn, Bridge Engineer of the Galveston, Houston & San Antonio Ry., had supervision of the erection.

DISCUSSION.

Question. For what capacity was the original viaduct built?

Mr. Alderson: It was built for a live load of 5,000 lb. per foot, with a concentration of 30,000 lb., and it was found to be amply safe for one-quarter of the present standard loading. Before reinforcing the viaduct the heaviest engine allowed to operate over it was a Mogul with 140,000 lb. on the drivers.

Q. With that 140,000 lb., would it correspond to Cooper's specifications E-30?

Mr. Alderson: Less than that, I think; I judge from the result of the stress sheets, and it has been over a year since I handled those sheets. As I remember, the stresses due to Cooper's specifications E-30 were just about equal to the allowable unit stresses, and the Mogul mentioned gave about the same stress, so it must be about equivalent to Cooper's E-30.

Q. Have you any figures showing the cost per ton for putting in that reinforcing?

Mr. Alderson: I have no exact figures. There are about 1100 tons of new steel in the structure, and it cost in the neighborhood of $130,000 in place.

Q. What unit stresses did you allow in figuring the strength of the old structure?

Mr. Alderson: Are you at all familiar with the Harriman Lines specifications? The unit stress they use at present is $8000\left(1+\frac{\text{minimum str.}}{\text{maximum str.}}\right)$, and on the old material we reduced that to $7000\left(1+\frac{\text{minimum str.}}{\text{maximum str.}}\right)$, this old material being iron and having been in service quite a while. That is our usual practice with old bridges. It was found, with the method of reinforcing, that the stresses came considerably below that. This is allowing one-fourth of the load on the outside trusses.

Q. Did you figure impact?

Mr. Alderson: The impact is considered in the allowable unit stress, which is a variation of the Launhardt formula.

Q. Do you mean 16,000 lb. for dead load?

Mr. Alderson: 16,000 lb. for dead load and 8,000 for straight live load. On old material it would be 14,000 for dead load and 7,000 for live load.

Q. How high are those stone piers?

Mr. Alderson: They are approximately 40 ft. above the river. It is 321 ft. from the river to the deck of the viaduct. The cantilever trusses are 30 ft. deep and the columns are 250 ft. long. That would make the piers about 40 ft. high.

Q. They look as if they might turn over.

Mr. Alderson: They do look rather slender, and they look more so when you get down and look at them. They look more like chimneys than piers.

Q. Does the water ever rise to that height?

Mr. Alderson: I do not know just how high the water does rise. Like all the streams in the southwest, the water comes up very quickly. Between the piers on the banks of the river it is 185 ft., and the river is probably 150 ft. wide and 5 ft. deep. It will rise 15 or 20 ft. over night, and the bases of the piers have been wet at times, but the water has never been anywhere near their tops, as far as I know.

Q. How are the winds in that section of the country?

Mr. Alderson: They are very high. During the original construction of the viaduct and also during its reinforcement, high winds increased the difficulty of the work. There is a flat rolling country adjacent to the canyon. A mile from either side of the bridge it looks like a little depression rather than a deep canyon.

Q. Was that reinforcing steel punched in the shop?

Mr. Alderson: Most of it was punched in the shop. The reinforcing material for the columns was made in the shop with the plates and angles riveted together and open holes in the other side of the plates and the other leg of the angles. On the Z-bar columns there were eight lines of holes, drilled for riveting on this reinforcing material about 8 in. apart for the full height of the column. The reinforcing angles and plates were clamped in place and used as a template for drilling these holes. In the connection for the transverse girders, the holes in the outstanding legs of the angles were drilled in the field. The girder was rested on shelf angles and wedged up to its proper height, and the holes in the connection angles drilled through the holes in the end of the girder. Wherever possible the material was punched and reamed in the shop, and wherever it was thought that trouble would occur, no attempt was made to catch old holes; where the attempt was made, it was very difficult to make the connection. All the center columns had a small bracket connected to each of the transverse struts, and the holes in the bracket would not quite match the old holes.

Q. Were air drills used?

Mr. Alderson: Yes, they had a compressor in the field. There were about 80,000 holes drilled and 137,000 rivets were driven in the field, all 7/8 in.

T. L. Condron, M. W. S. E. (Chairman): I suppose the wind stresses had been properly cared for in the original.

Mr. Alderson: Yes; the design was checked very carefully for wind stresses. The bridge was inspected several years ago, and everything was found to be in good condition after it had been subjected to high winds for seventeen or eighteen years. So the old wind bracing was considered safe.

One unfortunate thing is that on account of the height of the structure it is almost imperative that trains should run over it very slowly, but it happens to be at a sag in the grade where operating conditions make it desirable to run fast. The rule of running slowly over the bridge has always been followed, and I think that has a good deal to do with its present very excellent condition. For a while they used to stop passenger trains in the center of the bridge and let the passengers get out and walk around, but that custom has been discontinued for a number of years.

W. C. Armstrong, M. W. S. E.: Was the structure designed to have no tension from wind stress?

Mr. Alderson: I cannot answer that question. I thought I had some new stress sheets here from which I could find out, but I am mistaken.

Mr. Armstrong: The point I had in mind in asking that question was the change in the conditions that introducing that center column makes in the tendency to produce tension on one side in case of wind.

Mr. Alderson: The center columns were designed to take dead load, live load, and traction stresses only. All the wind was assumed to be taken by the outside columns. Under the live load alone there is something like ¾ in. compression in this column. The unit stress in that column due to dead and live load was much greater than it was in either of the outside columns, because in the outside columns an extra section was required to take care of wind stress. The top of the center column, on account of this greater unit stress, had a motion up and down relative to the outside columns, of about ¾ in. The center column is connected to the horizontal struts but not to the diagonal rods. These struts seemed flexible enough to allow that center column to compress without carrying any load to the outside column at all, and at the same time they are stiff enough to hold it transversely.

Mr. Armstrong: Would not that tend to increase the tension on the windward side when there was a train load on the bridge and take into account the wind load, because the load taken by each outside truss would be less than when there was no center column? The load that would tend to counteract the tension would be less.

Mr. Alderson: That matter was looked into, and it was found, as stated before, that the viaduct was designed for a load of about Cooper's specifications E-30; the load for which it was reinforced was Cooper's E-55. Roughly speaking, that would be about one-half, or twenty-seven and a half on the outside truss, and the outer columns are anchored on the assumption of the live loading being Cooper's E-25. So the present conditions in the outside columns are about what they were designed for.

Mr. Armstrong: Suppose you were to run a light load or take a train across that viaduct which would offer the same exposure to wind pressure that you had without the center column.

Mr. Alderson: When figuring the anchorage for viaducts, a live load of 800 lb. per ft. was assumed to resist overturning, instead of the standard load. So, to get the maximum uplift, a very light live load is used and combined with the wind stresses.

Mr. Condron: In other words, I suppose you figure zero live load and maximum wind load.

Mr. Alderson: That is what it approximated to.

Mr. Condron: That is the usual way.

E. N. Layfield, M. W. S. E.: Are the Harriman Lines specifications the same as published in the *Railroad Gazette* about five years ago?

Mr. Alderson: I think they are. Several years ago the *Railroad Gazette* published a series of articles on the Harriman Lines standard bridges, and I think it is likely if they published the Harriman Lines specifications five years ago, they are the same that are in use today.

Andrews Allen, M. W. S. E.: Following up the question raised by Mr. Armstrong on the calculation of wind in this viaduct, it looks to me as though the introduction of the center column weakens the structure against lateral or wind pressure, whatever the original method of calculation. If the work had been done by adding an A-frame at the bottom, as was originally contemplated, instead of adding a center pier, this would not have been the case, it seems to me, because the weight now carried at the center column would have gone to the outside piers and you would have had this additional weight available against an uplift on the windward side. As it is, you can readily see that even with the light train load originally figured, as against wind overturning, whatever that load was, half of it originally went down the outside column. Under present conditions only three-sixteenths of the load would go down the outside column, and the wind stresses would all have to be carried through the bracing, which is not connected to the center column, into the outside columns. Now, then, whatever the original method of calculation, you will see that you have less live and dead load available against the wind uplift than you had before, and your center columns do not add to the stability of the structure as a whole. I do not doubt but that the anchorage was properly calculated and that the structure is sufficiently stable at present, but I wanted to call attention to the fact that so far as I can see, the stability of the structure is less now than it was before the changes were made.

Mr. Condron: There is also more anchorage required now than before.

Mr. Allen: Yes, that is true. I have had a case recently in which I put center trusses into a bridge designed at about the same time as the Pecos viaduct. The trusses were 10 ft. apart, as in this case, and we added a middle truss supporting the center of the ties. Our calculations were made in exactly the same way and the same arrangements were followed for making the interior trusses independent of the lateral system. The center trusses went in with no difficulty and proved a great deal cheaper and easier to erect than any method of reinforcing the original trusses.

Mr. Condron: Did you carry central posts, then, in those towers?

Mr. Allen: We did not have any towers, fortunately.

Mr. Alderson: That is very true, but I remember in figuring these towers that they are more than ample. The towers under the cantilever had four anchor bolts. I have forgotten exactly the diameter, but they went down twenty odd feet into the pier. It was found that the structure was entirely safe against wind. If the original structure was designed with a live load of 800 lb. per ft. to resist overturning by the wind, that would be 400 lb. carried on each girder, and if we use the same live load on the structure with a center girder, that would be 3/16 of 800, or 150 lb. per ft., which would be only a difference of 250 lb. per linear ft. live load to resist uplift.

Take the case of a 65 ft. span and a 35 ft. span, making 100 ft. There would be half of that, or 50 ft., carried to one bent. That would mean only 12,500 lb. difference in the uplift, due to adding the center column. There is easily that margin of safety in the original anchorage.

I cannot recall any of the exact figures, and the stress sheets were not in shape so that I could get the data ready for to-night.

I. F. Stern, M. W. S. E.: It seems to me that Mr. Allen has overlooked one particular point, to which Mr. Alderson called especial attention. Mr. Alderson spoke of ¾ in. compression in the center columns. He also called attention to the fact that these columns were connected to the cross braces and not to the diagonal, and that the cross braces took that deflection without any trouble. Now let us go back to our condition of the wind on the tower. There is the vertical load against the tower, and you consider, as I suppose Mr. Allen does, the center leg and one of the outside legs as active. That, of course, decreases the moment arm and there would be a possible uplift, but that would only be if the entire bracing system were between those columns. According to Mr. Allen, the horizontal struts are able to take that deflection up to

¾ in. without any appreciable weakening of the connection, and the diagonal connections or diagonal members of the lateral bracing are still between the two outside columns. Now the tendency of the column on the windward side would be to rise, which could not rise (assuming that they are to be connected) until it compressed the outside leg. As the diagonal lateral connections are only between the two outside columns, I do not think that we have the weakened condition as stated by Mr. Allen or by Mr. Armstrong. I think that is one fact which they have not taken into consideration.

I am much interested in the paper, as the C. & N. W. Ry. Co. has done considerable work in the matter of strengthening of old bridges. I think any of us who have old structures to look after have that same proposition. We had a viaduct at St. Peter, Minnesota, that had been in use, I think, since 1881 or 1886. We had twenty-six 46 ft. lattice girder spans and they were spaced about 12 ft. centers. It became necessary to run heavier power over the line, and the question of reinforcing became a vital one. After mature deliberation, we found that the best thing that we could do was to double up the trusses. We ordered enough new deck plate girder spans for one-half of the bridge, and started putting those in after we put in cross girders somewhat similar to those Mr. Alderson described. The points of bearing not being over the columns, we had to have heavier cross girders. We did not find it necessary to reinforce the columns in this case, as they seemed strong enough for the additional load. We then took out the lattice spans we had in there, took those ashore, doubled them up and made a new span, each consisting of four girders, so that we had two of them under each rail. After this was done we carried them out and dropped them in place, using two derrick cars. We were in good shape for derrick cars at that particular time, so that we could use two, one from each end, and we found we were able to handle the work very quickly and economically. We considered the proposition and we might have used the gallows frame used by Mr. Alderson, but with the two derrick cars the operation is so much easier that in all cases where it is possible it pays to use that extra derrick car.

Mr. Condron: Is there anything else that can be added?

It is not often that we have the pleasure of having Professor Baker with us. Professor Baker may like to remark on the solidity of those piers that were shown on the screen. They are all right now that we know there are some anchor rods down there.

Ira O. Baker, M. W. S. E.: I have heard about this Pecos viaduct, because one of my graduates was engaged in the first erection, and I think he was also on the second.

I am not familiar enough with the work, however, to make any remarks worth listening to at this time. I have been much interested in the discussion and observing how the work was done. It is a different kind of work than we do in the recitation room.

IN MEMORIAM

GEORGE NIAL EASTMAN, M. W. S. E.

Died June 14, 1910.

George Nial Eastman died at Riverside, California, June 14, 1910, at the age of 34.

He was born at Arkona, Ontario, December 10, 1874. When quite young he moved to Michigan, where he attended school at Fort Gratiot and Imlay City, graduating from Imlay City High School in 1892, at the age of 18. That same year he entered the Mechanical Engineering Department of the Michigan Agricultural College at Lansing, and completed his course in 1897, with the degree of Bachelor of Science.

GEORGE NIAL EASTMAN, M. W. S. E.

In April, 1898, he entered the employ of the Chicago Edison Company, in the Construction Department, but was transferred to the Engineering Department in February, 1899, where it was recognized that he had an exceptionally keen, analytical mind. In the latter part of 1899 he was selected to succeed Mr. T. B. Gaylord as Chief of the Chicago Edison Company's Testing Laboratory, which position he retained until July, 1905, when he left on a trip to Europe in the interest of the company. At the time of his departure for Europe his health had shown signs of failing, but the trip did not remedy the difficulty. Shortly after his return to Chicago, in September, 1905, he went to California, where he made a brave fight for health until the time of his death.

Mr. Eastman was the author of a number of papers, among which are:

"Grounding of Alternate Current Systems." Proc. Western Society of Engineers, April, 1903.

"Development of new forms of Illumination and their possible influence on central stations." Read at the Association of Edison Illuminating Companies, Mt. Washington, N. H. September, 1902.

"Protection and control of large high-tension alternating current distributing systems." Read at International Electrical Congress, St. Louis, 1904.

"Relation between length of arc, voltage, and candle power in enclosed arc lamps, and the effect upon efficiency of arc lamps by varying the size of carbons." Read at Association of Edison Illuminating Companies. New Castle, N. H., August-September, 1904.

He became an Active Member of the Western Society of Engineers May 20, 1904, and an Associate of the American Institute of Electrical Engineers November 22, 1901. In 1902 Mr. Eastman married Miss Fay Wheeler, of Lansing.

This brief outline of the education and work of Mr. Eastman serves only to indicate his professional possibilities, had not his career been cut short.

(Credit is due The Edison Round Table for the illustration and some of the data of this sketch.)

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS

Special Meeting March 22, 1911.

A special meeting of the Society (No. 738) was held Wednesday evening, March 22nd. The meeting was called to order at 8:15 p. m. with President Chamberlain in the chair and about 75 members and guests present.

The President stated that the object of the special meeting was to receive and pass upon a report and resolutions referred to the Society by the Board of Direction, in regard to the status of the work performed by the State Geological Survey, and the Department of Mines at the University of Illinois. The report and resolutions as originally drawn up were slightly amended, and as passed by the meeting are here presented:

Chicago, Ill., March 8, 1911.

To the Western Society of Engineers:

In accordance with the provisions of a resolution passed by the Society on February 1, 1911, from which the following is quoted:

> "Whereas, The Western Society of Engineers has been especially instrumental in bringing about the establishment of a Geological Survey for the State of Illinois, and the establishment of a Department of Mines at the University of Illinois; and,
>
> "Whereas, The Society having been interested in these organizations, and in view of their importance to the general public, be it,
>
> "Resolved, That a committee, composed of not less than three members of the Society, be appointed to inquire into the status of the work performed by these organizations, and that such committee report the results of its examinations to the Society with such recommendations as may seem to be desirable."

The undersigned appointees under the above resolution report as follows:

It has found it impossible to consider the status of the Department of Mining Engineering entirely separate from that of the College of Engineering and the Illinois Engineering Experiment Station, for the reason that the work is inter-related in such manner as to permit of no separate consideration. Therefore, it has been necessary to take account of the engineering work of the University as a whole.

Our observation, regarding the Geological Survey, is as follows, after which the engineering work at the University will have attention:

GEOLOGICAL SURVEY.

Your committee, after a thorough investigation, is compelled to speak with praise and commendation of the work of the survey, and makes the following recommendations:

1. Improvement in character of the Survey's bulletins and other publications, as follows:

(a) Greater promptness in issue. Under present conditions it appears that there is frequently a period of many months between the time that the manuscript is submitted and the printing of the publication.

(b) That styles of composition differing from the present standard used in state publications should be employed, as the judgment of the Director would dictate.

The improvements recommended could probably best be secured by the publications of the Geological Survey being classified under what is known in the state printers department as fourth class matter, and it is recommended that this be done.

2. The requirements of modern industry demand the consideration of many engineering and technical problems in connection with the development of the state's natural resources. In this work, the best results may be attained by the retention, in a consulting and advisory capacity, of experts, especially familiar with the peculiar features of such various industries. At the present time, for such work, the Survey wisely avails itself of the service of the faculty of the State University. It would, however, in some instances, be to the advantage of the work if other experts could be called upon, and the committee recommends that the Director of the Survey avail himself of best available talent to promote both economy and efficiency in the work.

3. The request for an appropriation of $51,000 per annum is endorsed as being necessary. In fact, the committee would be disposed to suggest even larger increase, if it appeared possible under present conditions for such larger sum of money to be provided.

DEPARTMENT OF MINING ENGINEERING.

Your committee finds that the work the Department of Mining Engineering is called upon to do has not been provided for by a proper appropriation of funds. When this department was established some two years ago, the University's estimate of the absolute cost of the work for two years was cut in two in making the appropriation, so that only one-half of the additional work involved by the creation of this department was provided for in that appropriation. The other one-half of the cost became a burden upon the funds of the College of Engineering, which were already inadequate.

Your committee finds that the work of the Department of Mines is scattered about in various buildings, wherever space is found for it, and that the department is sadly in need of better quarters and more funds.

There has been a very satisfactory growth in the number of students taking the mining course and the prospect for its marked success is apparent, although the present inadequate equipment has caused some who desired to take such a course to go elsewhere.

Your committee recommends the following:

1. That a very liberal increase in appropriation be made for the development and support of this department.

2. That at the earliest possible date, plans for a building for the department be prepared and money appropriated for its construction. The present condition is not conducive to efficiency and economy.

As previously stated, the work of the Department of Mining Engineering cannot be considered except in connection with the entire College of Engineering. Consequently, while this committee had no instructions to consider the College of Engineering, it was of necessity compelled to give some attention to it and takes great pleasure in expressing appreciation of the work of the College and confidence in its management. The committee sincerely hopes the legislature will comply with the requests made for its support and improvement.

Few citizens perhaps realize what a tremendous factor in the state's prosperity the manufacturing industries have become. In 1900, Illinois had reached third place in the Union, in value of its manufactured product. The value of manufactured products was three and a half times that of agriculture, while about an equal number of its citizens were engaged in the two vocations.

Illinois is no longer a farm, but has reached out to cover all lines of industry.

The state needs for its development a large increase in facilities for training young men for the opportunities in all lines of industry and the College of Engineering is a great factor therefor.

CONCLUSION.

INCREASE OF TAX RATES.

Your committee realizes that the foregoing recommendations are similar in character to many appeals which have been made in behalf of the University and Geological Survey. It also believes that many of our citizens feel that these institutions are getting their proper share of the state tax levy and that anything in the way of an appeal for increased appropriation is the expression of a desire to obtain a larger share of the state's income, which, if obtained, must necessarily be taken from some other equally worthy cause, and for that reason the institutions in question should be satisfied with such funds as have been appropriated.

It is the conclusion of your committee, however, that the foregoing is an inadequate and erroneous conception of the matter. It appears that the real difficulty is due to the fact that the population, wealth, business, and industrial activities of the state are increasing rapidly, and this necessitates that the public activities and institutions of the state be called upon for larger and more highly developed performance; which, however, cannot be had without increased appropriation of money for the various purposes, and this money cannot be had without an increase in the amount of taxes which are collected. Thus, the trouble is not necessarily that the University and the Geological Survey fail to get their share of the public funds, but that the various public activities of the state are all inadequately supported and provided for.

If it were a fact that the citizens of the state consider that they are overburdened with taxation, it would be difficult to provide increased revenue. Your committee, however, is unable to discover that there is a feeling that the state taxes are too high. The per capita tax for state purposes is so small compared with the total tax paid, that the limitation of such educational work on the score of economy is not good business.

As indicating the feeling of at least part of the citizens toward the proper support of the work of the State University and the Geological Survey, is the attitude of certain industries toward the work of the Engineering and Agricultural Experiment Stations. People familiar with and interested in the development of the clay industries, have demanded the enlargement of experimental and instructional work in these lines at the University, with a realization that the compliance with such demands necessarily involved the expenditure of additional money, which must be provided for by taxation. The same is true, only in a much larger and important measure, of the agricultural interests of the state, which have demanded and secured the extension of the University's work in lines of interest to them. Other examples of this fact may be available, but your committee thinks that these two instances are sufficient to show that when the people of the community realize that similar valuable results will follow the development of those industries and activities in which they are interested, they will be equally ready to pay therefor. Increases in the tax rate for such purposes do not lessen, but enlarge the wealth.

It is the conclusion of your committee that a large proportion of the people of the state have given this matter no thought whatever, and that another important portion, which realizes the significance of it has failed to acquaint its representatives in the assembly with its wishes and have left the state legislature and the Governor to labor under the impression that the people of the state are more interested in the decrease of the tax rate, than in the development of their own property and the education of their children.

Respectfully submitted,

A. BEMENT,
L. C. FRITCH,
W. W. CURTIS.

ILLINOIS STATE GEOLOGICAL SURVEY.

Whereas, The Western Society of Engineers having among its membership many engineers who are interested in and concerned with the mineral resources of the state, has a peculiar interest in the activities of the Illinois State Geological Survey; and,

Whereas, A committee of the society, having recently examined the work of the Survey, has reported in terms complimentary of it; and,

Whereas, The value of the work to the industries of the state justifies increased expenditure for its advancement;

Be it Therefore Resolved, That the Western Society of Engineers hereby commends the work which has already been accomplished by the Illinois State Geological Survey, and urges upon the legislature of the state the importance of granting liberal appropriations for its further support.

Be it Also Further Resolved, That the Secretary of the Society forward a copy of these resolutions and of the report of the committee to the Governor of the State, to the Chairman of the Appropriations Committee of the House, and to the Chairman of the Finance Committee of the Senate, and that they be published in the Proceedings of the Society.

THE ILLINOIS STATE UNIVERSITY.

Whereas, The College of Engineering and Engineering Experiment Station of the University of Illinois have been established by the state for the purpose of advancing the educational, scientific, and technical interests of Illinois; and,

Whereas, The Western Society of Engineers, an organization conducted for the purpose of improving the social, scientific, and technical status of its members and of broadening the profession of engineering, is interested in the welfare of the College of Engineering and its allied activities; and,

Whereas, The Society has recently appointed a committee from among its members to visit the University and to report to the Society concerning the work which is being done there and the absolute needs of the College; and,

Whereas, This committee has now presented its report; and,

Whereas, It appears that the growth of the College and Station, as represented by the increased number of students in attendance and by the demands for engineering research, has created a necessity for room and equipment and for means whereby the work may be extended beyond that which has yet been supplied; and,

Whereas, The trustees are asking the legislature to supply an increased allowance for maintenance, and to appropriate money sufficient for the construction of a building for engineering;

Be It Therefore Resolved, That the Western Society of Engineers finds satisfaction in the progress which is being made at the University of Illinois in upbuilding its College of Engineering and in making of greater value the work of the Engineering Experiment Station; and,

Be It Further Resolved, That it is the sense of the Western Society of Engineers that the legislature might very wisely make liberal provisions for the maintenance and extension of the College of Engineering and the expenses of the Engineering Experiment Station, and for the construction of a building of such dimensions as will relieve the present crowded condition of the College; and,

Be It Also Further Resolved, That the Secretary of the Society forward a copy of these resolutions and of the report of the Committee to the Governor of the State, to the Chairman of the Appropriations Committee of the House, and to the Chairman of the Finance Committee of the Senate, and that they be published in the Proceedings of the Society.

Dr. Goss expressed the appreciation of the College of Engineering of the University of Illinois at this evidence of the interest of the Western Society of Engineers, through its committee, in the University and its work. Mr. F. W. DeWolf, also, on behalf of the State Geological Survey, gave expression of like sentiments to the Society and its committee.

The special meeting then adjourned.

EXTRA MEETING MARCH 22, 1911.

An extra meeting of the Society (No. 739), being a joint meeting of the electrical section of the Society and the Chicago Section A. I. E. E., was held Wednesday evening, March 22d. The meeting was called to order after the short session of the special meeting (No. 738) with G. T. Seely presiding.

Mr. Caryl D. Haskins, of the General Electric Company, Schenectady, N. Y., was introduced who read his paper on "The Engineer and War." Discussion followed from W. L. Abbott, W. F. M. Goss, FayWoodmansee, Morgan Brooks, F. J. Postel, G. M. Mayer, R. F. Schuchardt, L. R. Pomeroy, and Col. L. D. Greene, with a closure from Mr. Haskins.

Mr. Schuchardt offered a motion, duly seconded and passed, that the Board of Direction of the Society be asked to consider the appointment of a committee to investigate the advisability of the Western Society of Engineers taking action on certain recommendations made in the paper by Mr. Haskins.

Mr. Abbott offered a motion that a vote of thanks be tendered Mr. Haskins for his valuable and interesting address. The motion was carried unanimously.

The meeting adjourned about 10:30 p. m.

EXTRA MEETING MARCH 29, 1911.

An extra meeting of the society (No. 740) and smoker was held Wednesday evening, March 29th. The meeting was called to order at 8:20 p. m. by President Chamberlain, with about sixty members and guests in attendance.

President Chamberlain addressed the meeting on the aims and progress of the Society, the change in the publication of the Journal to a monthly, and the necessity of the members assisting the Publication Committee by submitting papers of interest to engineers for presentation at the meetings and publication in the Journal.

Mr. Ernest McCullough, chairman of the Entertainment Committee, followed with some remarks as to the desirability of increasing the social feature of the Society, and asked for remarks from the meeting as to how this may best be accomplished. Others also offered remarks along these lines.

Mr. Wm. Artingstall described, with the aid of blackboard sketches, some features of construction of the La Salle street tunnel, which consists of a duplex steel tube partially lined with concrete to be sunk in a trench excavated in the bed of the river, and afterwards connected with the land sections of the tunnel at each end.

The meeting adjourned about 9:30, when refreshments and cigars were served.

REGULAR MEETING APRIL 5, 1911.

A regular meeting of the Society (No. 741) was held Wednesday evening, April 5th. The meeting was called to order at 8:15 by President Chamberlain, with about fifty-five members and guests in attendance.

The minutes of the regular meeting of March 1st and the special meeting of March 22d were read and approved.

The Secretary reported from the Board of Direction the following list of new applications:

No. 22. Frank H. Stowell, Chicago.
No. 23. James W. Kern, Jr., New Orleans.
No. 24. Raymond L. Faithorn, Chicago.
No. 25. James Edward Cahill, Chicago.
No. 26. Wallace L. Zachow, Chicago.
No. 27. David J. Johnson, Terre Haute, Ind.
No. 28. Chester B. Lewis, Chicago.
No. 29. Charles S. Rogers, Galesburg, Ill.
No. 32. Charles A. Budd, Chicago.
No. 33. W. A. Dorcas, Chicago, transfer.
No. 34. Julian B. Freeman, Chicago, transfer.
No. 35. Meyer Fridstein, Chicago.
No. 36. Edward H. Bangs, Indianapolis, Ind.
No. 37. Egbert F. Manson, Freeport, Ill.
No. 38. Oswald A. Tislow, West Lafayette, Ind.
No. 39. William H. McGann, Chicago.
No. 40. Frederic R. Charles, Richmond, Ind.
No. 41. George M. O'Rourke, Tutwiler, Miss.
No. 42. Carl B. Williams, Chicago.

Also that the following had been elected into membership:

1910.

No. 4. James Welden Walter, Post City, Texas, Junior Member.
No. 67 Robert C. Schwarz, Chicago, Junior Member.
No. 85. Wm. J. Bennett, Chicago, Associate Member.
No. 88. James C. Pinney, Jr., Milwaukee, Wis., Associate Member.
No. 100. Frank M. Smith, Mishawaka, Ind., Member.
No. 110. Edwin C. Reeder, Chicago, Associate Member.
No. 111. Paul Lippert, Chicago, Associate Member.

1911.

No. 7. Welland F. Sargent, Oak Park, Ill., Member.
No. 13. John A. R. Daniels, Freeport, Ill., Associate Member.
No. 20. Fred K. Brewster, Oxford, Wis., Member.
No. 30. J. C. Worrell, Minneapolis, Minn., transferred to Associate Member.
No. 31. Edward Haupt, Chicago, transferred to Associate Member.

The President then introduced James S. Stephens, M. W. S. E., who read his paper on "Dynamics of the Flying Machine." Discussion followed from M. B. Wells—Sexton, E. A. Rummler, W. A. Blonck, W. E. Symons, A. von Babo, H. B. Wild, W. H. Beattys, with a closure from the author.

The President then introduced C. W. Morgan, Jr., M. W. S. E., who read an abstract of his paper, "Determination of Mean Radial Readings from Round Pattern Charts."

As the hour was late, the President invited discussion by letter to this paper.

The meeting adjourned at 10:10 p. m.

EXTRA MEETING APRIL 12, 1911.

An extra meeting of the Society (No. 742) was held Wednesday evening, April 12th. In the absence of the President, the Secretary called the meeting to order at 8:15 p. m. with about thirty-five members and guests present. Mr. Bement offered a suggestion, endorsed by Mr. Dart, that Prof. H. H. Stoek be invited to preside, and there being no objection, Prof. Stoek took the chair. There was no business before the meeting.

The chairman made a few preliminary remarks and introduced Mr. George S. Rice, who read his paper on the "Proposed Experimental Coal Mine of the U. S. Bureau of Mines." Discussion followed from the Chairman, Messrs. A. Bement, A. J. Saxe, J. A. Garcia, with a written communication from Mr. DeWolf of the Geological Survey.

The meeting adjourned about 10:15 p. m.

J. H. WARDER,
Secretary.

American Society of Mechanical Engineers.

The regular meeting of the American Society of Mechanical Engineers will be held in Pittsburg, Pa., May 30th to June 2d inclusive. E. D. Meier, president.

Plans for the meeting are being arranged by a local committee consisting of E. M. Herr, chairman, First Vice-President Westinghouse Electric and Manufacturing Company; George Mesta, President Mesta Machine Company; John M. Tate, Jr., President Tate, Jones & Co.; Chester B. Albree, President Albree Iron Works Company; D. F. Crawford, General Superintendent Motive Power, Pennsylvania Lines; Morris Knowles, Consulting Engineer; Elmer H. Hiles, Secretary.

The headquarters will be at the Hotel Schenley and the Society is fortunate in being able to arrange to hold its professional sessions at the Carnegie Institute, located near by and a most attractive meeting place and rendezvous for such an occasion.

The committee on meetings of the Society has provided sessions of an unusually interesting character particularly adapted for an industrial center like Pittsburg. The papers to be presented at one session will be on the subject of "The Mechanical Engineering of Cement Manufacture," following which there will be a visit made to the plant of the Universal Portland Cement Company. Another session will be devoted to the discussion of "Machine Shop Practice," when the special subjects of small machine parts and the development of milling cutters will be discussed. A visit will be made to the Westinghouse works. At one professional session, papers relating to steel works machinery with special reference to blowing engines and forging presses will be presented. Practically an entire day will be spent on an excursion on the rivers in order that the members and guests may have an opportunity to see the enormous industrial development in and about Pittsburg, for which a river trip will afford exceptional opportunities.

While there will be much of an engineering nature to occupy the attention of the members, ample provision is being made for entertaining the visiting ladies.

It is interesting to note that a meeting of the Society has not been held in Pittsburg since 1884.

G. M. B.

THE AMERICAN INSTITUTE OF MINING ENGINEERS.

The usual spring or summer meeting of this Society will be held this year at Wilkes-Barre, Pa. This will be the one-hundredth meeting of the Institute, and it is eminently fitting that this meeting be held where the Institute was first organized in May, 1871, forty years ago. Apart from such considerations, there is much of interest in and about Wilkes-Barre. The headquarters will be at the Glen Summit Springs Hotel about ten miles distant, on the Lehigh Valley R. R., well up on the mountain side, with magnificent views of the Wyoming Valley. Wilkes-Barre is on the Susquehanna River and is the center of the most productive anthracite coal regions in the United States.

The terrible Wyoming massacre of July 3, 1778, was at this point, between the American colonists and the English, with Indian allies. There is much of beautiful scenery and of historic interest in the neighborhood to attract the casual visitor, but members of the Institute will find yet more of interest in evidence of the professional work of mining engineers and metallurgists.

The first session of this meeting of the Institute will be held Tuesday evening, June 6th. An efficient local committee, consisting of Messrs. W. A. Lathrop, R. V. Norris, and S. D. Warriner will assist the officers of the Institute in making arrangements for the entertainment of those attending the meeting.

BOOK REVIEWS

THE SOCIETY OF ENGINEERS, INCORPORATED, LONDON, ENGLAND.

The Society of Engineers was established in May, 1854. and the Western Society of Engineers has in its library many volumes of its Transactions. The Civil and Mechanical Engineers' Society was founded May, 1859. These two Societies were amalgamated and incorporated in 1910, and the Transactions for 1910, edited by A. S. E. Ackerman, Secretary, have lately been received and added to our library. Some interesting and valuable engineering papers are published in this volume, as follows:

Electricity from the Wind. Arthur H. Allen.
Engineers and Empire Development. C. R. Enock.
Inspection and Testing of Engineering Materials and Machinery. C. W. V. Biggs.
Reinforced Concrete Retaining Walls. E. R. Matthews.
Up-to-date Roads. R. O. Wynne Roberts.
Sewage Disposal Ideals. W. C. Easdale.
The Working of the Roads Development Act, 1909. Reginald Brown.
Public Slaughter-houses. S. M. Dodington.

When these papers were presented a general discussion followed, which was duly reported and published with the original paper. Some illustrations are introduced, and the book has an attractive and interesting appearance, as well as intrinsic value of the papers themselves as high-grade engineering literature. W.

MINE RESCUE STATION COMMISSION OF ILLINOIS. The first report of the Mine Rescue Station Commission of this state has been made to the Governor and the General Assembly, and covers the work accomplished during the five months, August to December, inclusive, 1910. This is a pamphlet of 30 odd pages, 6 by 9 in., with some illustrations of the stations built and of the rescue car used to convey the rescue corps as may be necessary from the station to the mine when its services may be needed.

The three stations established are at LaSalle, Illinois, for the northern coal district—at Springfield for the central part of the state—and at Benton for the southern district. Selections have been made of suitable and qualified men as Superintendent and Assistant Superintendent for each of these stations. These men have received instruction and practical training at the Urbana Station in the use of helmets and other rescue apparatus, under Mr. R. Y. Williams, M. W. S. E., of the U. S. Bureau of Mines. The six men who are to have charge and care of the state stations were also sent to the U. S. Bureau of Mines at Pittsburg for further instruction. They have also attended lectures at the State University under Prof. H. H. Stoek, M. W. S. E., of the State University, Department of Mining.

The subject of equipment was of much concern to the Commission, as until very lately there was not much knowledge of what was available, where it was to be had, and what was the best to be secured for use at the stations in Illinois. The report shows that in the matter of helmets there are two different makes manufactured in this country at Pittsburg, and two other helmets made in Europe. Samples of these helmets have been secured and are being tried at Urbana, but there is need of better facilities for testing such apparatus before purchasing and to determine the comparative operating cost of the different styles of such apparatus now available, or that may be submitted by inventors in the near future.

"The rescue stations are intended to serve two distinct purposes:

First, to furnish a trained corps of men to assist at a mine in case of accident.

Second, to train men in the use of rescue appliances so that ultimately there shall be at every mine in Illinois a corps of men who can enter a mine with a suitable rescue outfit."

The plans of the buildings of the rescue stations show provision made to domicile the men who are in attendance under instruction in rescue work, and provision is made that at all times there may be a dozen or more men in attendance receiving instruction in rescue appliances and rescue methods.

The report closes with the following recommendations:

> "As a result of our experience thus far in carrying on the work of the Mine Rescue Station Commission, we believe that the efficiency of future work can be materially increased by amending the Act creating the Commission in the following particulars:
>
> 1. That the work of training may be extended, the Rescue Commission should be authorized to move the rescue cars from time to time from the stations to other mining centers and to give instruction in rescue work similar to that given at the rescue stations. In order that this may be carried on efficiently and the rescue stations at the same time kept properly manned, the commission should be authorized to have such additional employes in connection with the cars and stations as experience may show to be necessary.
>
> 2. Rescue work in America is as yet a novelty and the choice of apparatus for carrying on rescue work is limited mainly to apparatus manufactured abroad. Experimentation is necessary in connection with the purchase of equipment and in the economy of its maintenance. At present the cost of maintenance is a serious item of expense and every means should be taken to lessen this expense as rapidly as possible. It seems very likely that this can be done by experimenting with different types of apparatus and with different chemicals for use in the apparatus. In order that the Mine Rescue Commission may carry on such experimental work as is needed, provision should be made not only for the regular

routine work of the stations as now contemplated, but for such experimentation as may be needed to assist in conserving the lives of the workers of the State and its resources.

3. A rule has been adopted by the commission that an assistant in a rescue station must have a certificate as mine examiner before he can take the examination required to become such an assistant. The salary of $75.00 per month as now allowed by the act creating the Mine Rescue Station is frequently not sufficient to warrant a man in giving up the position he already holds. It is, therefore, recommended that the salary of the assistant for each station be increased from $75.00 to $100.00 per month, in order that the best men possible may be attracted to the work at the station.

4. It has been found during the present year that members of the commission have been compelled to devote more time to the work of the commission than was contemplated in the original act. The time for which per diem is allowed should, therefore, be extended from 25 to 50 days per year, said per diem to apply to all members of the commission."

THE ART OF ROADMAKING. By Harwood Frost, B. A. Sc., Member American Society of Mechanical Engineers; Member Society for the Promotion of Engineering Education. 544 pages, including index and appendix, 6½ in. by 9¼ in.; illustrated. New York; The Engineering News Publishing Co., London; Constable & Company, Ltd. 1910. Cloth. Price $3.00.

This work on road building, ancient and modern, is systematically divided, consisting of three parts and an appendix, or four distinct parts in all:

Part I is devoted to Preliminary Considerations, and is mostly theoretical, with the exception of a portion of Chapter III, which is devoted to the requirements of a good pavement. While Part I contains much of interest to the civil engineer as well as to the practical road-builder, its value consists largely in the enunciation of the principles and economics of road building to the non-technical and non-professional man interested in this subject. This part consists largely of a systematic compilation of experiments and tables for which due credit is given in foot-notes, together with statements of the books from which extracts have been made, thus making Mr. Frost's work a comprehensive index to the various technical works treating of different phases of the subject.

Part II is devoted to the subject of country and suburban roads, and outlines at some length the proper methods of locating country roads, together with the determination of maximum grade for various classes of traffic, and the methods of overcoming grades. It discusses in detail the building and cost of earthwork, and enters into the subject of drainage at greater length than is common in most works on road-building. Chapter V of Mr. Frost's book, or that portion dealing with foundations and drainage, is one of the most valuable chapters of the work. This feature of road building in country-road work is one that is commonly overlooked and destroys to a great extent work which otherwise would be of a permanent character. Highway bridges and retaining walls are discussed in a general way with copious references to technical works on these subjects.

Chapter VI is devoted to the materials used in the construction of roads, and discusses at length the values and essential qualities of road-making materials.

Chapter VII on earth, gravel, sand and clay roads is devoted largely to the experimental roads which the Government has made of these materials, together with a discussion of the various tools and machines necessary for this class of work.

Chapter VIII discusses hard and broken stone roads, much of which is historical, referring to the early works of Telford and Macadam, together with methods of repairing and curing defects, and costs of hard roads.

Chapters IX, X and XI are devoted to mountain roads and improvement and maintenance of country roads, together with modern methods of control and prevention of road dust. On this latter subject, the various recent practices in the use of calcium chloride, residuum oils of petroleum, coal tar and asphalt macadam binders are discussed at length. Chapter IX is devoted to the state-aid laws and consists principally of references to the laws of various states in this regard, together with the specifications used in some of the eastern states under the state-aid road laws.

Part III (Chapters XIII to XXII inclusive), discusses at length city streets and pavements. It is of value in its statements of the advantages and disadvantages of the different street-paving materials—granite block, brick, creosote wooden block, asphalt and concrete—with a view of assisting the reader to select the proper materials for the different conditions of city traffic. One chapter is devoted, also, to the cleaning and sanitation of city streets, showing the best practices in the large cities of this country and Europe.

The fourth part, or appendix, after discussing specifications and contracts and pavement guarantees, is largely statistical and is of interest for reference purposes. A comprehensive index completes the volume and makes its use as a reference book convenient.

In general, the work does not claim much as to originality, but shows a careful and pains-taking study of the entire subject. While most of the work is elementary in its character, it is, as the author states, in the title page, written in non-technical language suitable for the general reader, and should find its proper place among supervisors, superintendents of streets and members of improvement boards interested in good roads and city pavements. It is a valuable book of reference for any one engaged in road building or street work, and should have a place in the library of every civil engineer engaged in such work.

O. P. C.

Drop Forging, Die Sinking, and Machine Forming of Steel. Joseph V. Woodworth. The Norman W. Henley Publishing Co., New York, 1911, 6½ by 9¼ in., 341 pages and 300 illustrations. Cloth bound. Price $2.50.

This book treats of Modern Shop Practice, Processes, Methods, Machines, Tools and Details. It is a practical treatise on the hot and cold machine-forming of steel and iron into finished shapes, describing the tools and appurtenances for the manufacture of duplicate forgings from bar and sheet metal. The range of work that can be made by such processes is very wide. There are innumerable parts of modern machine construction which need to be duplicated in quantities and which can be hot or cold forged in drop-press work. These can be turned out by the use of proper dies and processes, so finished as to require a minimum of machine work after forging, thus resulting in cheaper production.

This book describes in a practical way, with many illustrations, the design and construction of dies, the operation of drop-forging, the machines used, etc. An extended index makes the book more valuable.

W.

The Temperature-Entropy Diagram. By Charles W. Berry, Asst. Prof. of M. E., in the Mass. Inst. of Tech., 3d ed., revised and enlarged. New York, John Wiley & Sons. Cloth, 7½ by 5 in.; pp. 393. Price $2.50.

This is a modern and up-to-date publication, treating of the application of the temperature-entropy diagram to problems met with by the engineer. Each of the various applications to be met is fully described and illustrated. The illustrated problems used have been specially calculated, so that they may agree with more recent practice. The volume is accompanied by a convenient table of symbols used in the text, and among the new matter presented is consideration of steam turbines and the boiler room.

The work is divided into chapters. In addition to the consideration of Reversible Processes, Effect of Irreversibility, and Temperature-entropy Diagram for Perfect Gases, special chapters are devoted to Steam, Superheated Vapors, Flow of Fluids, Mollier's Total Energy-entropy Diagram, Mixtures of Gases and of Vapors, Hot-Air Engines, Gas-engine Cycles, Gas-engine Indicator Card, Non-conducting Steam-engines, Multiple-fluid or Waste-heat Engines, Actual Steam-engine Cycle, Cylinder-efficiency, Liquefaction of Vapors and Gases, Air-compressors and Air-motors and Refrigerating Processes. A. B.

MODERN FRAMED STRUCTURES. By J. B. Johnson, C. W. Bryan and F. E. Turneaure, 9th edition, Parts I and II. Part I, 6¼ by 9¼ in., 328 pages. Cloth. Price $3.00. Part II, 6¼ by 9¼ in., 588 pages. Cloth. Price $4.00.

Johnson's Modern Framed Structures has for years been a standard text and reference book on bridges, and needs no introduction to the engineering profession.

Heeding the popular demand for books of a convenient size, the authors have, in this revision published in three parts, broken away from the time honored custom of a one-volume standard.

Part I treats of stresses in simple structures and covers about the same ground as Chapters I to VIII and Chapter XV of the old edition. The plan originally adopted of carrying the graphical and algebraic methods along together has been adhered to with an increased amount of attention being given to the graphical process. There is also much more attention given to influence lines; possibly more attention than is warranted by their questionable value in the solution of simple structures. The chapter on Elementary Statics might very profitably have been considerably shortened, as a fuller knowledge of the subject than could be gained from this chapter is assumed throughout the book. The chapter on Roof Trusses is almost entirely new and gives the complete solution, graphical and analytical, of the common forms of roof trusses. The text is quite full and very easily followed. The chapter treating of bridge trusses, while partly rewritten and somewhat expanded, especially by added examples illustrating the formula, follows the original text quite closely. Under Conventional Loads an exact uniform live load system in connection with influence lines is developed which will be found more troublesome than wheel loads. In view of the fact that an equivalent live load based on the ¼ space moment gives results for main members accurate to within 3 or 4 per cent, it seems useless to complicate the work by having a different live load for each panel point of a truss. After all of this painstaking we guess off 50 per cent to 80 per cent of the live load and call it impact and are not greatly disturbed if it be 3 per cent or 4 per cent more or less.

In the chapter on Lateral Trusses, Trestles and Towers, the text is quite full and explicit. The stresses in various forms of portals are given in terms of the load. There is also a good discussion on wind and tractive stresses and centrifugal force.

Part II treats of structures which are statically indeterminate. As compared with chapters of the former edition, the present work has been greatly extended in scope and entirely rewritten. The chapter on

Continuous Girders is quite complete but would have been much easier reading, for most users of the book, if the explanation had been a little fuller. There might profitably have been added an analysis of a few of the special cases that are constantly arising in concrete work. The chapter on Swing Bridges is also quite complete, giving in general a comparison of results by exact and approximate formula. There might, however, have been added a simpler approximate formula for the solution of partially continuous rimbearing bridges. The chapter on Arches gives the analysis of the various types by the usual methods. Chapter V is probably the most exhaustive treatment in English on suspension bridges. It will, however, be of actual value to very few. The chapter on Miscellaneous Problems in Statically Indeterminate Structures will be of especial interest to the practicing engineer, as a number of perplexing problems that are continually arising are fully analyzed. In Chapter VII the Analysis of Secondary Stresses is given in sufficient detail to be followed without undue labor. There are also several illustrative examples given. This volume is especially valuable as a reference book. J. C. S.

TRANSPORTATION IN EUROPE. By Logan G. McPherson, Johns Hopkins University. New York, Henry Holt & Co., 1910. Cloth, 5 by 7¼ in., pp. 285, including index. Price $1.50.

The author of this book had unusual facilities for acquainting himself with his subject at first hand, as he was for some time in Europe in 1909 in a semi-official capacity with the National Waterways Commission. The commission made a report on their European investigations, and this book is based on that formal report, rearranged to make it more acceptable to the general reader.

The titles of some of the chapters are: Land Roads and Interior Waterways. Development of the Railways. Railway Passenger and Freight Tariffs. Concerning Freight Traffic. Phases of Government Control. Summary of the Situation on the Continent. Transportation in England.

Although much has been written in this country as to the economy of water transportation, as shown in its extensive development in Europe, the author indicates his belief that a great amount of this water transportation could not be maintained in competition with railway transportation, if it were not for the fostering care of the Government, and the charges upon and restrictions of rail traffic, taxes, and the like, imposed by the Government. This seems to be particularly the case in France.

The chapter "Concerning Freight Traffic" is full of interest. In Germany the railways must forward quick-service freight from the receiving station within one day after receipt, and carry it at the rate of nearly 200 miles a day. Ordinary freight must go forward within two days after receipt, and be moved at not less than a certain minimum distance per day. If these obligations, fixed by the Government, are not fulfilled, there is a deduction from the charges of transportation.

"The great difference in the conditions attending the movement of freight traffic in the United States and in continental Europe makes any specific comparison of freight rates exceedingly difficult. . . . It is a fairly safe generalization that the American shipper is better treated, receives better service, and relatively more service for his money than the shipper of any country of continental Europe."

The author explains clearly the conditions and reasons for the differences in size and capacity of the freight cars in continental Europe as compared with the United States. Nevertheless, there seems to be an atmosphere of depreciation of European railway practice and in favor of what is done in this country, and the thought occurs to the reader, has the author a prejudice against Government owned and regulated railways, as is the general case in Europe, and does he favor more the broader conditions of railway operations in this country? Whether the reader of this book will entirely agree with the author, or be opposed to his conclusions, the reviewer cannot but say he has found the book informing and interesting reading. W.

LIBRARY NOTES

The Library Committee desires to return their thanks for donations to the Library. Since the last publication of the list of such gifts, the following publications have been received:

MISCELLANEOUS GIFTS.

Myron C. Clark Publishing Co., Chicago:
  Engineering Law, Vol. I, The Law of Contract, Haring. Cloth.
John Wiley & Sons, New York:
  Temperature Entropy Diagram, Chas. W. Berry. Cloth.
C. F. Loweth, M. W. S. E.:
  Record of Construction of Missouri River Bridge at Mobridge, S. D. Cloth.
McGraw-Hill Book Company, New York:
  Kinetic Theory of Engineering Structures, D. A. Molitor. Cloth.
Wm. Seafert, Aff. W. S. E.:
  The Manufacture of Hydraulic Gypsum, M. Glasenapp. Pam.
Paul P. Bird, M. W. S. E.:
  Report of Department of Smoke Inspection of City of Chicago, February, 1911. Pam.
Sanitary District of Chicago:
  Proceedings of Board of Trustees, 1910. Cloth.
American Telephone & Telegraph Co:
  Annual Report of Directors to Stockholders, 1910. Pam.
E. P. Goodrich, New York:
  Report Upon the Elimination of Surface Freight R. R. Tracks of the N. Y. C. & H. R. R. R., Etc. Pam.
Slason Thompson, Chicago:
  Railway Statistics of the United States for the year ending June 30, 1910. Pam.
A. Bement, M. W. S. E.:
  Illinois Coal Reports, 1881-1909, 29 Vols., Cloth. Transactions American Institute of Chemical Engineers, Vols. 1 and 2, 1908 and 1909. Cloth.
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  An Elementary Course of Civil Engineering, D. H. Mahan, 1846. Cloth.
  Iron Truss Bridges for Railroads, Wm. E. Merrill, 1870. Cloth.
George Westinghouse, Pittsburg, Pa.:
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Interstate Commerce Commission:
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  Bibliography of Science Teaching. Pam.
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  Bulletin No. 445. Pam.

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Production of Lead in 1909. Pam.
Production of Salt and Bromium in 1909. Pam.

U. S. Bureau of Mines:
Bulletin No. 8, The Flow of Heat Through Furnace Walls. Ray & Kreisinger. Pam.

EXCHANGES.

Massachusetts State Board of Health:
Annual Report, 1909. Cloth.

Ohio Highway Department:
Sixth Annual Report, 1910. Cloth

Iowa Geological Survey:
Annual Report, 1909. Cloth.

Canada Department of Mines:
Bulletins 4 and 5, Nos. 71 and 82. Pams.
Chrysotile-Asbestos, Its Occurrence, Exploitation, Milling and Uses.

Missouri Bureau of Geology and Mines:
Biennial Report of State Geologist, 1910. Pam.

New Jersey Sanitary Association:
Proceedings, 36th Annual Meeting, December, 1910. Pam.

Wisconsin State Board of Forestry:
The Taxation of Forest Lands in Wisconsin. Pam.

Western Australia Geological Survey:
Bulletins 38 and 39, 1910. Pams.

Institution of Electrical Engineers, London:
Journal, February, 1911. Pam.

Royal Philosophical Society of Glasgow:
Proceedings, Vol. XLI, 1909-10. Pam.

American Society of Civil Engineers:
Year Book, 1911. Cloth.
Transactions, March, 1911. Pam.

Ohio Geological Survey:
Bulletin No. 11, 1910. Cloth.

Pacific Northwest Society of Engineers:
Directory, 1911. Leather.

American Railway Bridge and Building Association:
Proceedings, 20th Annual Convention, 1910. Cloth.

American Gas Institute:
Proceedings, Vol. V, 1910. Cloth.

Brookline, Mass., Water Board:
Report for Year 1910. Pam.

Massachusetts Railroad Commission:
42nd Annual Report, 1910. Cloth.

Tennessee State Geological Survey:
Administrative Reports of the State Geological Survey, 1910. Pam.
Bibliography of Tennessee Geology, Soils, Drainage, Forestry, Etc.

Illinois State Geological Survey:
Bulletin No. 16, Oil, Coal, Lead, Zinc, Etc. Cloth.

Philadelphia Bureau of Surveys:
Partial Report for Plan for Collection, Purification, and Disposal of Sewage for Entire City. Bds.

Rose Polytechnic Institute:
29th Annual Catalogue, 1910-11. Pam.

Society of Engineers, London:
Transactions, 1910. Cloth.

April, 1911

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Journal of the

Western Society of Engineers

VOL. XVI MAY, 1911 No. 5

OIL INVESTIGATIONS IN ILLINOIS.

By

RAYMOND S. BLATCHLEY.*

Presented March 1, 1911.

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Introduction.

In the short time available, it is possible to outline only very briefly the investigations by the State Geological Survey, covering the present immense oil fields and other prospective oil areas. There will be given first, a brief history of operations in Illinois, then a short statistical statement, an account of the origin and accumulation of oil, an outline of the investigations, and finally a discussion of the commercial features.

Historical Statement.

The first oil excitement spread over the eastern United States in the early part of the sixties and extended westward to Illinois. In 1865 the first *wild-catting* took place in Clark county, about eight miles north of Casey. Here several wells were drilled in attempts to locate oil and gas, but the work was abandoned. A very small amount of oil was found, which, perhaps, would have been greater had proper casing been used. Water drowned out the oil and prevented an earlier discovery of the present extensive field. Oil was found about this time in a sump in a mine near Litchfield, Montgomery county, but its exploitation was delayed until 1882. A small field of 30 wells, that produced several hundred barrels

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*Geologist in charge of oil studies, Illinois State Geological Survey.

annually, was outlined between 1882 and 1889. Production is wholly abandoned at the present time. The oil came apparently from the Pottsville sands.

A gas field was discovered along an anticline in the Niagara limestone near Pittsfield, Pike county, during 1886. About 30 wells have been drilled and 24 found to be productive in an area covering 4 by 10 miles. Similar prospecting took place near Sparta, Randolph county, in 1888. Several good gas wells were found in the Chester formations of the Mississippian series of rock. The field was further extended in 1906 and 1908 to the north of Sparta where about six wells produced small amounts of oil. Production is all but abandoned now.

Further wild-catting took place in Crawford county between 1900 and 1904, but this field was not opened until 1906. The Casey region was redrilled in 1904-1905 and oil was found in commercial quantities. The fields spread rapidly and gradually merged into the deeper and deeper pools of Crawford and Lawrence counties, until at the present time they cover a narrow strip from 2 to 8 miles wide and about 60 miles long, with an area of about 240 square miles.

Oil was found early in 1908 in a mine near Centralia, Marion county. Prospectors were attracted to the territory and several shallow productive wells were drilled. Later, in 1909, an oil and gas area was tapped north of Sandoval in the same county. This developed rapidly in 1910, and promises at the present time to be an important producer of oil in Illinois. The oil comes from a depth of about 1,600 feet in a sand that corresponds to the Kirkwood of Lawrence county. There are now about 40 producing wells which yield about 3,500 barrels daily.

Oil and gas have been found in small quantities at other points over the state at Greenville, Carlinville, Jacksonville, Pocahontas, Marissa, Mascoutah, Eldorado, etc. Active drilling is now going on at DuQuoin, Nashville, Greenville, Carlyle, and other localities.

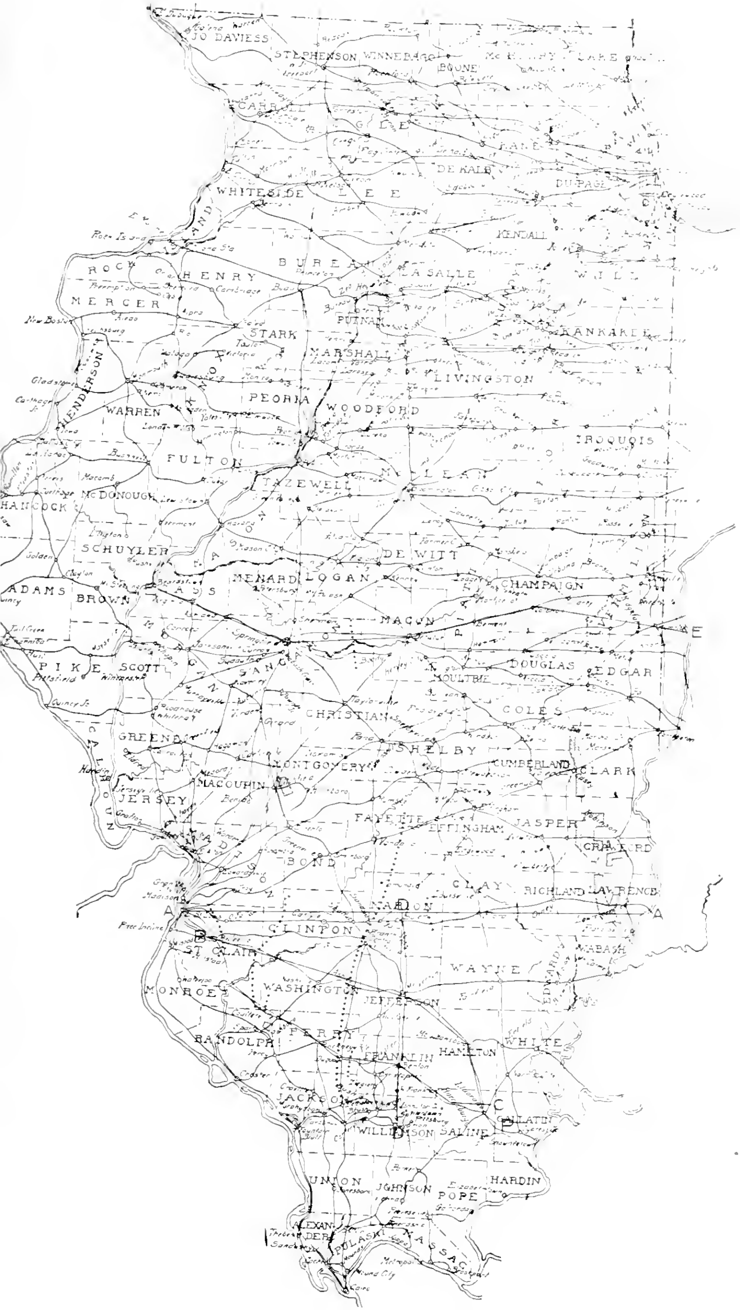
Rank of Illinois.

Illinois gained ninth place for production and value of oil in 1906, and third place for both in 1907. Since then the state has held third place for production and second for value and has been excelled only by California and Oklahoma. Up to January 1, 1911, about 18,636 wells had been drilled for oil and gas in the state, of which 15% were barren. The remaining 85% have produced, since 1905, about 128,000,000 barrels of oil, valued at about $82,000,000. The present daily output of the fields is about 85,000 barrels. The Ohio Oil Company (Standard) controls most of the production.

The Origin and Accumulation of Oil.

The origin of oil is uncertain, but two general theories, called the inorganic and the organic, attempt to explain it. One is largely unacceptable and even the other has many faults. The inorganic

Plate 1.



Map of Illinois, showing oil fields, cross-section lines, position of structural terraces, and of the La Salle anticline.

theory attributes the origin of petroleum to the breaking down of certain carbides of metals by the action of water in the interior of the earth. It assumes a later condensation of the resulting gases as they arose to cooler strata near the surface. This hypothesis does not apply to all oil fields as well as the organic theory. This second theory is based on the decomposition of vegetable and animal matter, particularly in the limestones and shales near the porous sandstones which now contain the oil. It is recognized that plants and animals were deposited in the accumulating muds and silts of centuries. These were shut off from the oxygen of the air and other destructive agents, so that, eventually, a peculiar distillation converted the carbon, and other constituents of the once living matter into oils and gases. The distillation was a matter of long ages, and the migration of oil to more porous reservoirs than the limestones and shales was a secondary step.

This circulation and accumulation of oil was accomplished by agents such as capillarity, gravity, and gas or rock-pressure. As the minute distillation proceeded, the oil was taken up under the influence of gravity and capillarity, and passed into porous sandstones. An important factor in the accumulation was the *lay* of the rocks. The sedimentary strata were deposited under water horizontally, or practically so, and the natural distillation of oil probably began while the beds were in that position. Subsequent folding of the strata formed series of arches or domes, offset by corresponding troughs or basins. The arches are known as anticlines, while the depressions are called synclines. When this folding took place, the water, petroleum, and gas within the sandstone formations were forced to move according to the laws of gravitation, and hence to distribute themselves according to their specific gravities. The water was the heaviest of the three fluids, and, therefore, sought the synclines as far as possible, depending, of course, upon the porosity of the sands. Its tendency was to displace the oil and gas, forcing the oil to float on the water and the gas to rise still higher. The oil was enabled to rise as far as the water extended up the slopes of the synclines, while the gas was able to free itself and rise to the highest place in the porous bed, usually the crest of the anticlines. The surface of the oil sand on the anticline may be pitted or undulating and this condition may affect an extensive area or only a few acres of ground. Though the general accumulation of oil and gas is governed by the anticline proper, covering many miles, the segregation of pools may be caused by smaller folds on the large one. This intricate system of synclines and arches on the parent fold is coupled with variation in the porosity of the sands, and the two conditions greatly affect the distribution of oil and gas. It is readily recognized that either factor may explain the local presence of dry holes within productive territory.

A segregation of oil may take place along a bench or sometimes called a structural *terrace,* much in the same manner as in the anticlines and synclines. The terrace, strictly speaking, is an interruption in the uniform dip of the sides of a basin, giving rise to an approximately horizontal plane. Such benches are to be found upon the sides of the great structural basin in southern and central Illinois. The water in the basin enables the oil to rise to the terrace, where it is trapped by friction. Any oil, originally in the sloping sand above the bench, may migrate farther up the general incline until it is caught by some other barrier.

In studying the theories and the actual facts in the oil fields, it is found that the oil and gas in the main fields occur along the crest of the La Salle anticline. That in Marion county occurs on a terrace or irregular dome. Enough information is at hand to show that wet sands predominate in Illinois and that the oil and gas are captive in the highest portions of the raised structure, according to the theory stated. It has been further shown that practically all localities in Illinois, yielding oil and gas to date, lie along anticlines, domes, or terraces. Therefore, the general conclusion follows that any area within the state, or out of it, for that matter underlain by suitable formations and these structural features, will bear investigation for the presence of oil and gas.

Investigations of the Geological Survey.

The Survey began an investigation of the main fields in 1908, with a view of determining certain peculiar conditions existing in the oil horizons. The elevations above sea level and logs of about 5,000 wells were taken in the southern half of the productive area. These records were plotted and contour maps were made upon each sand. The maps, about fifteen in number, are being studied at the present time and an effort is being made to find the relation of the quantities of oil, salt-water, porosity of the sand, etc., to the structural features of the sand. It is believed that these maps will be of large service in the further development of this important field, and also that they will yield valuable data for the study of the laws governing the genesis and accumulation of oil and gas. The report will incude also the commercial features peculiar to the Illinois fields.

The work upon the report of the main fields has been interrupted to prepare a paper in response to many inquiries received by the Survey, relative to the conditions and localities favorable for the accumulation of oil and gas outside of the main fields. They have been, chiefly, questions regarding structural features, such as anticlinal folds, dips of coals, oil seeps, depths to the oil sands, etc. The determination of structural features outside of the main fields seemed formidable because of the immense expanse of flat territory, so covered with drift as to conceal the sequence of formations and practically all evidence of folding and faulting. The only means available were to construct several geological cross-sections of Illinois and to point out the irregularities occurring in some key horizon. The folds serve to outline prospective drilling areas to the oil operators, but the adjoining basins or slopes are not so favorable.

Plate 1 indicates the location of the sections which were constructed.

The general sections were chosen along lines showing the greatest number of wells and coal bores, and at the same time crossing the great structural basin of Illinois. The identification or correlation of various beds in each section presents a general idea of the stratigraphy and structure of the lower portion of the state. The four sections presented here include only a portion of the work accomplished by the Survey. The cross-sections were constructed by plotting records with uniform symbols and scale. They are located with respect to their distance from the nearest town and to their position above sea level. Correlation lines drawn between similar formations in adjoining records, picture any rise or fall. Thus section A-A, giving the most complete geological data across the state, presents a picture of the great structural basin of central Illinois. The section is drawn from St. Louis, Mo., to Vincennes, Ind., and crosses the Sandoval and Lawrence county oil fields. In this and the other sections there is indicated a conspicuous spoon-shaped basin, with its long axis paralleling the La Salle anticline and extending from the north line of Stephenson county, past La Salle, Cerro Gordo, Lovington, Olney, and continuing to the southwest county of Indiana. The deepest part of the basin lies in the vicinity of Wayne, Hamilton, Edwards, and White counties, where the rocks lie comparatively flat and the basin is broad. Towards the basin, with local exception, all the rocks of Illinois and of western Indiana dip gently. Attention is called to the key horizon or the No. 6 coal, which is definitely known over about one-half of the section, while the remainder is doubtfully identified.

The accompanying printed sections indicating the order and character of the strata, were published by Bain,* and are modified slightly to agree with later conclusions.

Overlying the consolidated rocks of the state, except in the extreme southern and northwestern counties, there is a varying thickness of glacial deposits or *drift*. These clays, sands, gravels, etc., are commonly encountered in drilling before hard rock is reached. Locally, they contain gas, but the pressure is usually slight and the life of the individual wells is short. While it is not possible in every case to absolutely exclude the possibility of these wells representing leakage from lower reservoirs, a sufficient explanation of them is believed to be found in the decay of woody material buried in the drift itself.

The stratigraphic section for southern Illinois is most important

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*Bain, H. Foster, Petroleum fields in Illinois in 1907: Bull. Ill. State Geol. Survey No. 8, pp. 273-312.

in the study of oil possibilities. The formations promising best production are indicated by italics and occur chiefly in the Carboniferous system. Possible oil *sands* are suggested also in the Ordovician and Silurian systems, especially in central and southern Illinois.

Northern Illinois Section.

This section is intended to be representative for that portion of the State lying north of Rock Island, La Salle and Kankakee.

Carboniferous. (Pennsylvanian.)	"Coal measures," mainly middle part; consisting of coal, shale, sandstone, and limestone; 575 feet thick; no known gas or oil. Unconformity.
Devonian.	Limestone; 150 feet thick. Unconformity.
Silurian.	Niagara limestone; dolomite; 335-388 feet thick; *containing frequent seepages of bitumen in the vicinity of Chicago.* Unconformity.
Ordovician.	Cincinnatian shales and limestone; 68-250 feet thick. Unconformity. Galena-Trenton; mainly dolomite, a little limestone and shale at the base; 300-440 feet thick; a very persistent *"oil rock" or petroliferous shale in the lower portion.* St. Peter sandstone; friable sandstone 150-275 feet thick; heavily water-bearing. Lower Magnesian dolomitic limestone; 450-811 feet thick; all but upper part known from well records; rests on Potsdam sandstone, known only from well records.

Central Illinois Section.

For the region south of Rock Island, La Salle and Kankakee, and north of the mouth of the Illinois River and Danville.

Carboniferous. (Pennsylvanian.)	"Coal measures," upper part; coal, shale, limestone, and sandstone; 600-700 feet thick. "Coal measures," middle part; shale, sandstone, and coal including approximately from "No. 2 coal" to "No. 6 coal;" 300 feet thick. "Coal measures," basal part (Pottsville equivalents), including coal, clay, shale, and sandstone; mainly the beds associated with the "No. 1 coals" of the western part of the State, and of irregular thickness, found in deep borings elsewhere; 50-150 feet thick; *small amounts of oil and gas reported, but origin not certain.* Unconformity.
Carboniferous. (Mississippian.)	Chester; irregular thickness of sandstone, shale and limestone, recognized in a few borings; generally absent in this territory; 0-50 feet thick. Unconformity. St. Louis, Salem, Ste. Genevieve; limestone, non-magnesian, partly cherty and partly oolitic; 50-100 feet thick. Osage group, Warsaw, Keokuk, and Burlington; shales and limestone, the latter often cherty; 250-350 feet thick; *crude petroleum in geodes near the top of the Keokuk.* Kinderhook; shales, limestones, and sandstones; 80-150 feet thick. Unconformity.
Devonian.	Limestone; 15 feet thick. Unconformity.
Silurian.	Niagara; dolomite; 50-120 feet thick; *gas at Pittsfield in Pike County, and oil seepage in Calhoun County.*
Ordovician.	Cincinnatian; shales; 40-100 feet thick. Unconformity. Galena-Trenton; dolomite; 300-400 feet thick; *oil seepage at Calhoun County.* St. Peter; sandstone; 130 feet exposed; heavily water-bearing.

Southern Illinois Section.

For the area south of the mouth of the Illinois River and Danville, including the principal oil and gas producing districts.

Tertiary.	Lafayette, Porters Creek and Lagrange; sands, clays, and ferruginous conglomerate found in extreme southern counties only; 150 feet thick.
Cretaceous.	Ripley; sands and clays in extreme southern portion of the State only; 20-40 feet thick. Unconformity.
Carboniferous. (Pennsylvanian.)	"Coal measures," upper part; coal, shale, sandstone, and limestone; 500-700 feet thick; *contains the oil and gas sands of the Westfield, siggins, and Casey pools.* "Coal measures," middle part; coal, shale, sandstone, and limestone; 400-650 feet thick; *including probably the lower pay of the Johnson Township pool in Clark County, and possibly the Robinson sand.* "Coal measures," basal part (Pottsville equivalents); sandstone, conglomerate shale, and thin coals; 50 to 500 feet thick; including the *Buchanan sand and probably the Robinson and Bridgeport sands, with the greater part at least of the productive sand of Montgomery County. The oil sand of Princeton, Ind., may possibly belong in this group.* Unconformity.
Carboniferous. (Mississippian.)	Chester group; limestone, shales and sandstones, usually three well defined limestones (non-cherty) and generally with red shale at the base; 500 feet thick; *includes the Kirkwood oil sand of Lawrence County; a gas sand at Vincennes, Ind.; the gas and oil sands at Sparta in Randolph County; the Tracy and McClosky oil sands of Lawrence County; the Stein and Benoist oil sands of Marion County; the Lindley gas sand, of Greenville, Bond County; and the oil sand of Oakland City, Ind., the last three mentioned sands being the equivalents of the Kirkwood sand.* Cypress; sandstone, massive, coarse-grained; fairly regular in a thickness of 80 to 150 feet; not known to have been prospected for gas or oil. Unconformity. Ste. Genevieve, St. Louis and Salem; limestone, partly cherty and partly oolitic; 250-400 feet thick. Osage group (Burlington, Keokuk, Warsaw); limestone often cherty with some shale; 200 feet thick. Kinderhook; mainly shale, some limestone; 50 feet thick.
Devonian.	Limestone, sandstone, shale; limited in outcrop to southern counties; 500-700 feet thick.
Silurian.	Niagara and Clinton; limestone; in southern counties only; 100-110 feet thick.
Ordovician.	Cincinnatian; limestone, shale, and sandstone; 100 feet thick. Unconformity. Galena-Trenton; limestone, non-magnesian; 80 feet thick.

It is not necessary to present the details of the stratigraphy along the A-A section. There is plainly shown the varying thickness of drift deposits, and particularly the thickening of the *Coal Measures*, or Pennsylvanian rocks, toward the basin. The upper rocks are characterized by coals, thin limestones, and shale. They are shown to be thickest in the south-central part of the state along the axis of the main basin or syncline. From this region they become thinner as the formations rise towards the borders of the state. This is due partly to surface erosion and partly to variation in original deposition.

The massive Pottsville sandstones underlie the Coal Measure proper and are a part of the Pennsylvanian series. The Pottsville sands are often interbedded with shales and hence the top is difficult to identify, owing to the merging of the sands with overlying shaly rocks. The correlations in the cross-sections were based, for the most part, upon the top of the thick sand, immediately underlying the conspicuous shaly rocks. There is also a usual absence of limestone strata in them, thus differing distinctly from the underlying Mississippian rocks. The several sections show that the Pottsville is practically absent west of an irregular line drawn from Springfield through Carlyle to Coulterville. It is also absent north of Springfield, except possibly in the vicinity to the northeast. A thickness of 450 feet along the C-C section, presented later, decreases to 300 feet along the A-A section, and to 50 or 100 feet along the E-E section. These sandstones are very productive in the main fields, and are called the Buchanan from the name of the farm on which oil was first found in that sand.

The Mississippian series lying in the Carboniferous, next below the Pennsylvanian, contains the most widely productive oil sands in the state. The upper part of the Mississippian series includes the Chester rocks, characterized by a succession of limestones, red shales, and sandstones. The top of these rocks is marked by the first limestone below the Pottsville. The red shales are important horizon markers with the oil men, signifying the approach to such sands as the Kirkwood, Tracy, and McClosky. The Kirkwood sand of Lawrence county, the Benoist sand of Marion county, Lindley sand of Bond county, and the Sparta sand of Randolph county, all belong to the same horizon and underlie the Chester red shales. Oil men scarcely ever drill below the Chester rocks and into the massive St. Louis limestones, or the *big lime*. In several cases, however, deep wells have been drilled in search of the Trenton or Niagara.

The oil of the main fields comes from the following sands:

County.	Name of sand.	Depth—feet.
Clark Edgar Cumberland Coles	Shallow	375— 500
Crawford	Robinson	750— 950
Lawrence	Bridgeport	850—1,000
Lawrence	Buchanan	1,300—1,400
Lawrence	Kirkwood	1,450—1,600
Lawrence	Tracy	1,690—1,750
Lawrence	McClosky	1,800—1,890

The structure of the cross-section is indicated by the *lay* of the coal. The coal outcrops several miles east of St. Louis, along the bluffs of the Mississippi; it dips gently from that point but irregularly at several places along the section. In the vicinity of Sandoval the coal is seen to lie rather flat and then dip suddenly into the deeper part of the basin. The new oil field at this town lies along that deformation, which extends southward to DuQuoin and possibly northward between Brownstown and Vandalia, Pana, and Tower Hill to Niantic. The rocks rise from the axis of the basin to the La Salle anticline at a fast rate, then decline gently and rise again into Indiana. The main oil fields of southeastern Illinois lie at the top of the anticline.* The formations below the No. 6 coal rise in a similar fashion and corroborate the structure. The Kirkwood sand correlation line indicates the sharp rise over the La Salle anticline.

It may be mentioned at this point that the survey has collected complete samples from about 20 wells over the main fields, from depths of 800 to 2,000 feet. Studies of these will almost certainly identify the No. 6 coal over the anticline and permit closer classification of all the oil producing formations.

The promising structural features along the A-A section are, the flat terrace at O'Fallon, the mild arch at Aviston, the slight arch at Carlyle, the irregular Sandoval and Odin terrace, and the Iuka fold.

The C-C section is plotted along a line from New Athens to DuQuoin, Benton, Rileyville, and Eldorado. It follows the Illinois Central Railroad closely between these points and is especially valuable since it is based on a large number of coal bores and mine records. There are several attractive structural features exhibited, especially one at DuQuoin. After passing the Coulterville syncline, the coal rises toward Pinckneyville and forms an anticline between there and DuQuoin. This is about six miles wide. The coal presents a remarkable dip of over 400 feet in about two and one-half miles, immediately east of DuQuoin. This offers excellent opportunity for the migration of oil into the anticline, and as several wells already drilled indicate, the sands on the slope are thoroughly saturated with water. The DuQuoin anticline extends to the southwest toward Murphysboro and is shown by the coal contours recently published by E. W. Shaw, on the Murphysboro quadrangle. From DuQuoin northward, it probably passes west of Tamaroa and DuBois, and between Nashville and Ashley. It is considered to be a continuation of the Sandoval terrace, already mentioned. The crest of this structure is higher at DuQuoin than at Sandoval and hence has a slope downward to the north of DuQuoin. At DuQuoin the dip is from about 400 feet above, to several feet below sea level, while at Centralia the dip is from sea level downward. The fold is narrowing in its axial width northward from DuQuoin.

The most promising structural features along this section are enumerated as follows:

1. The Marissa flat.
2. The Tilden anticline.
3. The DuQuoin anticline.
4. The second DuQuoin arch.

The D-D cross-section was drawn from Marion in Williamson county to Salem in Marion county. It crosses the southern slope of the Illinois basin and shows the position of the coal from south to north. The dip along the southern slope of the basin is about 50 feet per mile. There is a slight flattening of the coal between wells 5 and 6. A terrace occurs between wells 8 and 9, south of Benton, and a slight bench is shown at well No. 11.

The E-E cross-section is the most northern one and is plotted along a line from Beardstown in Cass county to the state line near Danville in Vermilion county. The section reveals the relations of the lower rocks of the western side of the state; the shallow character of the Illinois basin in the northern part of the state; and the La Salle anticline. It is particularly valuable from a stratigraphical point of view, since the Chester rocks are shown to be absent around Springfield and present to a small degree in the basin at Decatur. The Pottsville is very thin along this section. The only significant feature in the structure exists at Niantic. A very small arch is shown in the No. 6 coal. It is noticeable that from this point eastward there is a rapid dip of the coal into the basin. It is suggested that the Niantic deformation may be a continuation of the Sandoval-DuQuoin terrace. All the formations show a decided rise into the La Salle anticline at Tolono. The crest of this arch is thought to be west of Tolono in the vicinity of Sadorous.

Other sections not presented here show similar features in the key horizon, and seem to corroborate the presence of the previously mentioned minor folds along the broad western flank of the Illinois basin.

Besides structural cross-sections, detailed contour maps on the No. 6 coal have been made of some areas. That for the new Sandoval oil field is presented here. The position of the coal in the several mines and wells along the western side of the county were noted, and also the surface elevations at each. Contours of 25 feet intervals were made from these data. The dips in the various directions are portrayed and warrant definite conclusions regarding the present and future drilling. The structure of the coal is further shown by the use of profiles drawn between prominent points on the contour map, in such position that they are at right angles to the dip. They are intended merely to make clear the mental picture to those who are not familiar with contouring.

The present active oil field near Sandoval seems to be bounded by the 125 foot coal contour, and the best area to further develop that field lies within the confines of that line. This includes the town of Sandoval and the area southeast of it. The most promising area, however, is in and about the crest of the dome-like structure in section 29. Oil has already been found in shallow sands in this structure but the lower sands are even more promising.

The similarity of the structure south of Centralia to that of

DuQuoin leads to the conclusion that a structural terrace exists slightly to the west of Centralia, and hence offers prospective territory. The so-called terrace is irregular but possibly continuous throughout Fayette, Marion, Washington and Perry counties.

Reference to Plate 1 indicates the position of various deformations discussed. It will be readily seen that the western flank of the Illinois basin holds promise of new oil fields, and that possibly the northern portion of the La Salle incline will bear investigation in the older formations. The center of the basin or main syncline of the state is not promising for prospectors. It has been sufficiently drilled at an aggregate expense that is astonishing, to corroborate the theories just explained. Future drilling should be based on the scientific investigation which has been outlined here.

COMMERCIAL FEATURES OF THE ILLINOIS FIELDS.

Introduction.

The successful growth of the Illinois oil fields may be attributed to the quiet efficiency of experienced and capable oil men. The business is divided into many branches, each of which, from the first step of leasing to that of an established production, requires careful and systematic attention. The enormous quantity of oil produced, the necessity of taking care of it properly and economically, and the many local conditions of development, distinguish this field from others. It has been truthfully said that "there never has been an oil field so well taken care of in so short a time, as that of Illinois."

The first step necessary to the development of any oil field is a business-like lease of the land, conveying distinct rights to both the landowner and the lessee. The successive steps of choosing well sites, drilling, shooting wells, and equipping oil properties, involve activities separate from each other, yet so connected that each is a necessary part of the whole. In fact, the Ohio Oil Company has separate branches for leasing, drilling, buying, pipeline discharge, telegraph, and for engineering.

The various divisions of the oil business, as presented above, are further discussed in detail in the natural order of the development of properties..

Leasing.

In contrast with the oil territories of the mountainous Appalachian regions and of the far West, Illinois is a drift-covered plain. All of it is either in cultivation or devoted to pasture. The land divisions are simple and uniform, and are based on the civil townships of 36 sections. Each section, as a rule, is divided into tracts of the multiple of 20 acres. The leasing of territory then starts upon a simple basis. The oil men deal entirely with individual land-owners, and leases are private bargains. While some of the territory is developed by land-owners, it is more often leased from the owner for a period of five years, with option of further lease as production continues. If adjoining property is untested at the time of leasing, the farmer usually receives a royalty of from one-eighth to one-sixth of future production, with the further stipulation that the drilling is to begin within six months to two years, or that a stated rental will be paid until the first well is drilled. If, on the other hand, the desired property lies near producing territory, a bonus is demanded in addition to the royalty and the reservation of the fee. The closer the farm is to good oil properties, the higher the bonus becomes; it averages from $10.00 to $40.00 per acre, but sometimes reaches $200.00 per acre. The land-owner retains surface rights of the land, except on the portion necessarily used by the operator for his equipment. Upon an 80-acre tract not more than 6 acres are necessary foı this. Thus, it is possible to farm and at the same time derive a good income from oil. It is agreed that the lessee shall be responsible for all serious damage to growing crops, and that all pipe-line shall be buried below plow depth. It is usually agreed that wells will not be drilled closer than 200 feet to any building. If gas wells are drilled on the farm, they usually provide the farmer with an income of $100.00 to $125.00 per year. After production is established, the lease becomes the most valuable part of the oil property. It is often sold, the price depending mainly on the number of producing wells and their average daily yield.

Choosing a Well Site.

The choosing of a well site is the next step after leasing. Wells are generally placed about 210 feet inside the property line. This varies, however, with different depths of sand. Wells in the shallow fields are often placed 100 feet from the line, but in the deep Lawrence county pools the distance is from 250 to 300 feet. An unwritten law in most fields requires the lessee to drill opposite producing wells on adjoining property. This *offsetting* is done to protect property lines and prevent drainage of oil from the lease. Should the lease be surrounded by wells of a neighbor it is the custom to offset all adjoining wells and leave the centers, 900 by 2,250 feet, on an 80-acre tract, to be drawn upon. The line wells then draw to good advantage, and unnecessary center wells are avoided. The distance between wells on the same lease depends on expense and other factors. In the Clark and Crawford county fields they are generally placed 450 feet apart, but in Lawrence county wells to the deeper sands are located 660 feet apart. The choosing of a site may be affected, furthermore, by sudden dips in the sand, by buildings, transportation facilities, irregularities of surface, or by water supply. The advance of oil operators into active coal fields of the state may necessitate selection of well sites so as not to endanger mines and their employes.

Drilling.

The third step in the development of oil properties is a contract between the operators and the drilling contractor, at a certain price per foot, dependent upon the locality and the depth of the desired sand. The contractor is held responsible for the well to the specified depth, or until it is determined whether the desired sand is productive. The contract states that drilling shall begin within a specified time.

The contractor is responsible for the purchase and construction of the derrick. He furnishes boiler, *string of tools,* fuel, water, drillers, and tool-dressers, and is held responsible for accidents. He must also clean out a producing well, and, after a successful shot, put it in order and pull the casing.

The operator, on his part, usually agrees to furnish conductor, drive-pipe, casing, tubing, and rodding. He provides for hauling the pipe and necessary accessories other than the driller's string of tools and rig.

When the contract for drilling is signed, the operations pass into the hands of the contractor, who in turn contracts with the rig-builder. The *standard* rig is most commonly used in the Illinois fields. The principal part of this is four strong uprights, held in position by ties and braces, and resting on strong wooden sills. This derrick is used as a support for the sheave or crown pulley, which must be of sufficient height—66 feet in the shallow fields and 72 feet in the deeper fields—to swing the long, heavy, drilling tools free from the derrick floor. Connected with the derrick are the bull-wheel and shaft on which is wound the cable supporting the drilling bit; the walking beam, giving vertical motion to the tools; the band-wheels, transmitting power from the engine to the moveable parts; and the sheds to protect the engine, bull-wheel, and shaft from inclement weather. The construction of the rig requires about three days and costs about $500.00 The same derrick can be used about twelve times, at an extra cost of about $100.00 each time, for tearing down and rebuilding and for additional repairs and materials.

The steel derrick is used in some portions of the field, though not extensively. The uprights are of steel and the braces and ties are of wire, cable, or steel rods. The sheds, shaft, and bull-wheel are wooden. The steel derrick is easily taken down and moved but its original cost is much greater than the standard derrick.

A portable drilling rig is often used in the shallow fields. The whole outfit as mounted on a heavy wagon includes a single high timber, fitted up as a derrick, while the remaining necessary parts are assembled in a compact manner back of it. This rig is not practical for deep sands or hard formations.

May, 1911.

The following costs of drilling are representative for the various pools:

Pools.	Cost per foot. Dollars.
Clark county	$0.80
Crawford county	0.80
Lawrence county—	
Bridgeport, with 10-inch drive-pipe and 6⅝-inch casing	0.80
Bridgeport, with 16-inch drive-pipe and 8¼-inch casing	1.35
Buchanan	1.35
Kirkwood	1.50
Tracy	1.50
McClosky	1.50

The drilling crew consists of 2 drillers and 2 tool-dressers, who work by pairs in shifts of 12 hours each. It is the duty of the driller to stay close to the mouth of the bore, regulate the cable and temper-screw when necessary, control the machinery, etc. The tool-dresser fires the boilers, attends to the engines, dresses or sharpens the bits, assembles the small tools, switches the bull-wheel cable, etc. The average daily wages of drillers is $5.00 and of tool-dressers $4.00. The time required to drill, shoot, clean, and put in order a well in the different pools is as follows:

Pool.	Days.
Clark country or shallow	4 to 5
Crawford county	10 to 12
Lawrence county	
Bridgeport	10 to 12
Buchanan	20 to 25
Kirkwood	35 to 45
Tracy	60 to 75
McClosky	60 to 100

Shooting the Well.

When the oil-bearing stratum has been tapped and found productive the driller notifies the operator, who in turn arranges with the agent of a nitroglycerine company to bring the explosive and shoot the well. After he has measured the sand accurately with a steel-line tape, he pours the nitroglycerine into long, tin shells holding 20 quarts each, and lowers them to the producing sand. The shells are conical at the lower end and concave at the upper, so as to fit snugly together. The top shell bears a water-proof percussion cap connected by a wire to an electric hand-battery above ground. The explosion opens a large cavity in the producing sand and cracks the bed for a wide radius, thus allowing the contained oil and gas to flow to the well. The greatest care is used in placing the shot in order not to disturb the overlying shales or the underlying sand, which usually contains salt water. The size of the shot depends upon the texture and thickness of the producing sand. A charge of 80 to 100 quarts is sufficient for the Illinois fields.

About ten seconds after the shooter has discharged the explosive there is a quick jar of the earth, followed by a muffled report. With a roar the gas pours forth from the well in a bluish-white streak, followed, shortly, by a column of oil and water. This rises slowly to above the top of the derrick, where it sprays out in the direction of the wind. The rattling of pebbles against the derrick, and the heavier thuds of large fragments on the ground is heard for several minutes. The column of oil subsides in a short time and the drillers cap the well or turn the flow into emergency tanks.

The torpedo company is held responsible for the well from the moment of taking charge, and, if a premature shot takes place through carelessness or neglect, must arrange to drill another well immediately near the same location.

The torpedo companies maintain manufacturing plants in each main field in isolated spots. Small storage magazines are maintained in other out-of-the-way places so as to distribute the supply and avoid large loss in case of accident. Large stock wagons supply the magazines and lighter wagons make distribution to the wells. The nitroglycerine wagon is built on strong but flexible springs, and is fitted with square padded cells for each 10-quart can of liquid. The shooter drives along unconcerned over bumps and ruts. I have ridden several times on the *dangerous wagon*, and have found it comfortable in comparison to other vehicles. Accidents are rare, but may be caused by collision or carelessness in pouring the liquid. A drop on the side of a can may be exploded by friction. The viscous liquid is safely poured by a steady hand.

Solid nitroglycerine in the form of a yellowish, transparent jelly has been used in Illinois, but the liquid seems to be preferred because of its explosive efficiency. The standard prices for the explosive are as follows:

Quarts.	Value. Dollars.
10	$25.00
20	40.00
30	47.50
40	55.00
60 and more, per quart	1.15

Other charges include 2c per foot for electric wiring, and in case of delay, an extra charge of $15.00 per day for the time of the shooter.

Lease Equipment.

Pumping.—After the well has been shot it is cleaned of debris, and a 2-inch tubing, containing a ⅝-inch sucker rod, is placed in the hole to the sand. If the well is the first one, the rod is set to pumping directly from the walking beam. If the well is one of several, it is connected to the power-house by a pumping jack.

Tanks.—The oil from the first well is sent to emergency tanks and from later wells to the lease tanks. The tanks are built of wooden staves and steel bands, and range upwards to 1,600 barrels capacity. The cost of the usual 250-barrel tank is about $90.00, and of the 1,600-barrel tank about $450.00. Second-hand tanks cost about the same and are preferred because they are saturated with oil. When several tanks have been built on a lease, sheds are placed over them for protection from evaporation. The average cost of these is about $60.00.

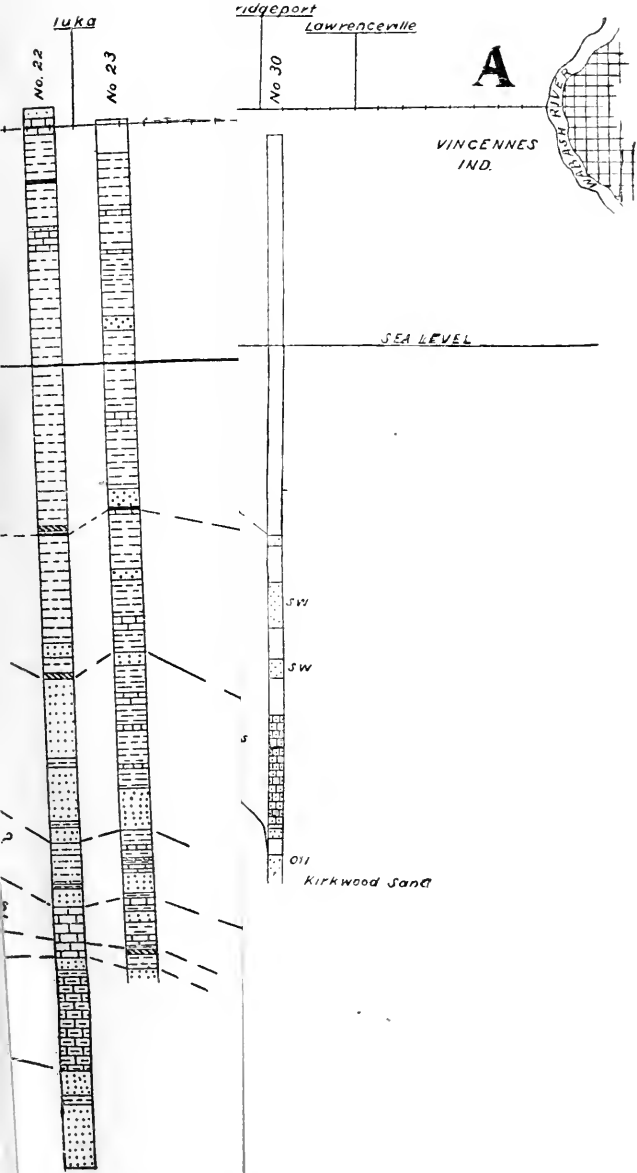
Loading racks.—The oil from a new field is generally sent by donkey-pump to the nearest railway loading-rack and is shipped by tank-car to the refineries.

Power and boiler-houses.—With several wells on the lease it becomes practicable to build a centrally located power-house for pumping them. The building has walls of wood or corrugated sheet-iron, and a floor of cement. A gas engine is installed at one end of the building, and at the other end an oscillating pull-wheel to give horizontal movement to the rods radiating from it to the different wells. The pull-wheel draws the surface rod toward the power and the weight of the sucker-rod in the well pulls it back, thus providing the necessary balance of work. A boiler-house is built for emergency use and for steaming the oil. The average cost of the power-house and boiler-house is about $1,200.00. The 25-H. P. gas engines cost $425.00; the 35-H. P. engines, $585.00; the Mascot power, $320.00, and the boiler, $385.00. One equipment serves as high as 40 wells, but usually only 25 to 30. The power man makes the rounds of inspection, cares for his engine, boiler and oil tanks, and makes a daily report.

Pull-rods and pumping-discs.—The surface pull-rods are generally made of steel or wire cable. They are supported in a level line to the well by posts of various lengths. Wells may be pumped in spite of intervening buildings by the use of angle-knees. Large flat, oscillating pumping discs are often used to overcome surface irregularities or obstructions, and for pumping across highways. They are connected to the power by large pull-rods, which move alternately and turn the disc through an arc of about one-eighth of a circle. Surface rods radiate from the disc to the wells.

Pumping-jacks.—The standard wooden pumping-jack, most commonly used, is substantially mounted over the well on heavy wooden sills. The workable portions resemble a right triangle, with the right angle pivoted and the acute angles attached to the sucker and surface rods. It serves as a lever to the power. Steel jacks are often used. With the home-made jack the angles are reversed and the action is one of pushing up. Light weight jacks cost about $10.00 and heavy ones about $17.00.

Plate 2.



Louis, Mo., to Vince

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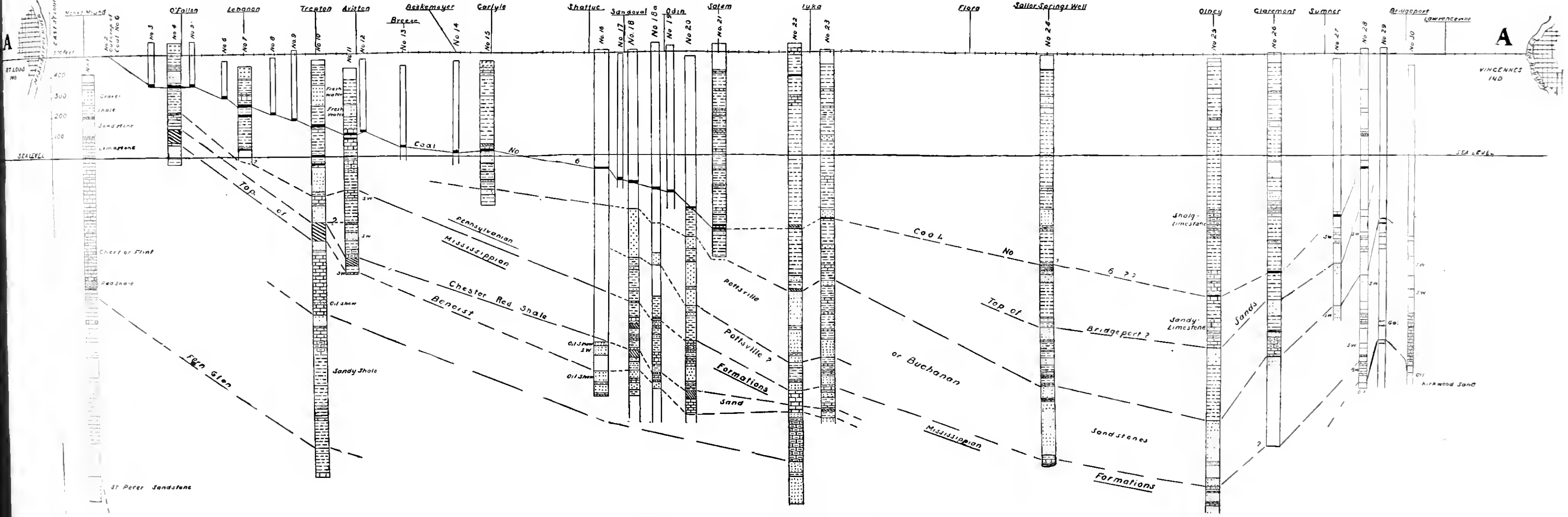
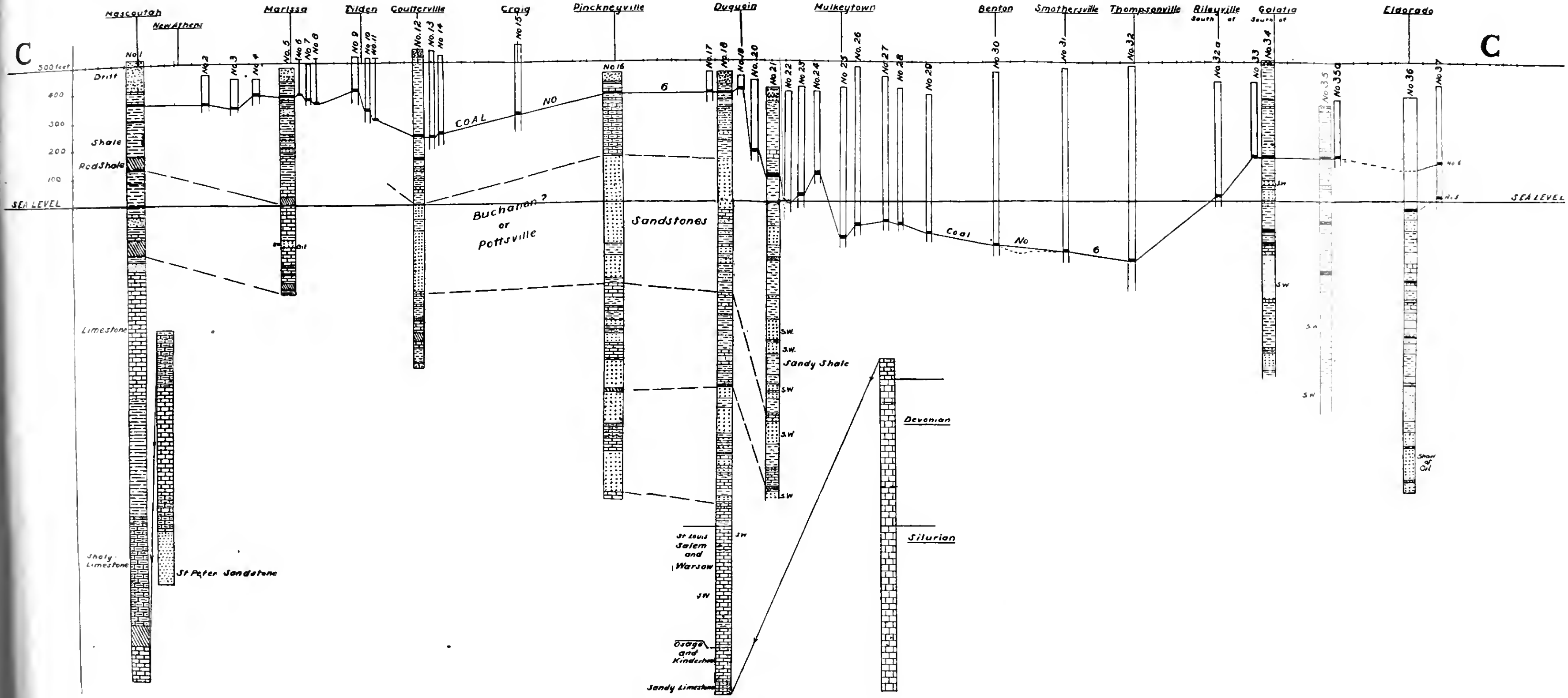


2. Cross-section A-A, from St. Louis, Mo., to Vincennes, Ind.



3. Cross-section C-C, from New Athens to Eldorado, Ill

Plate 4.

ATE GEOLOGICAL SURVEY

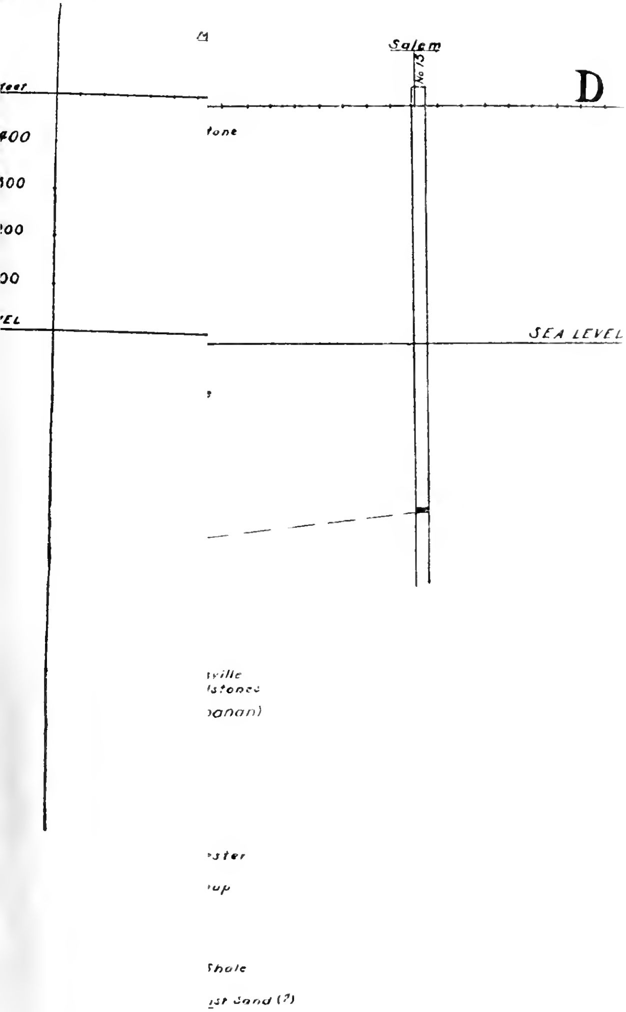
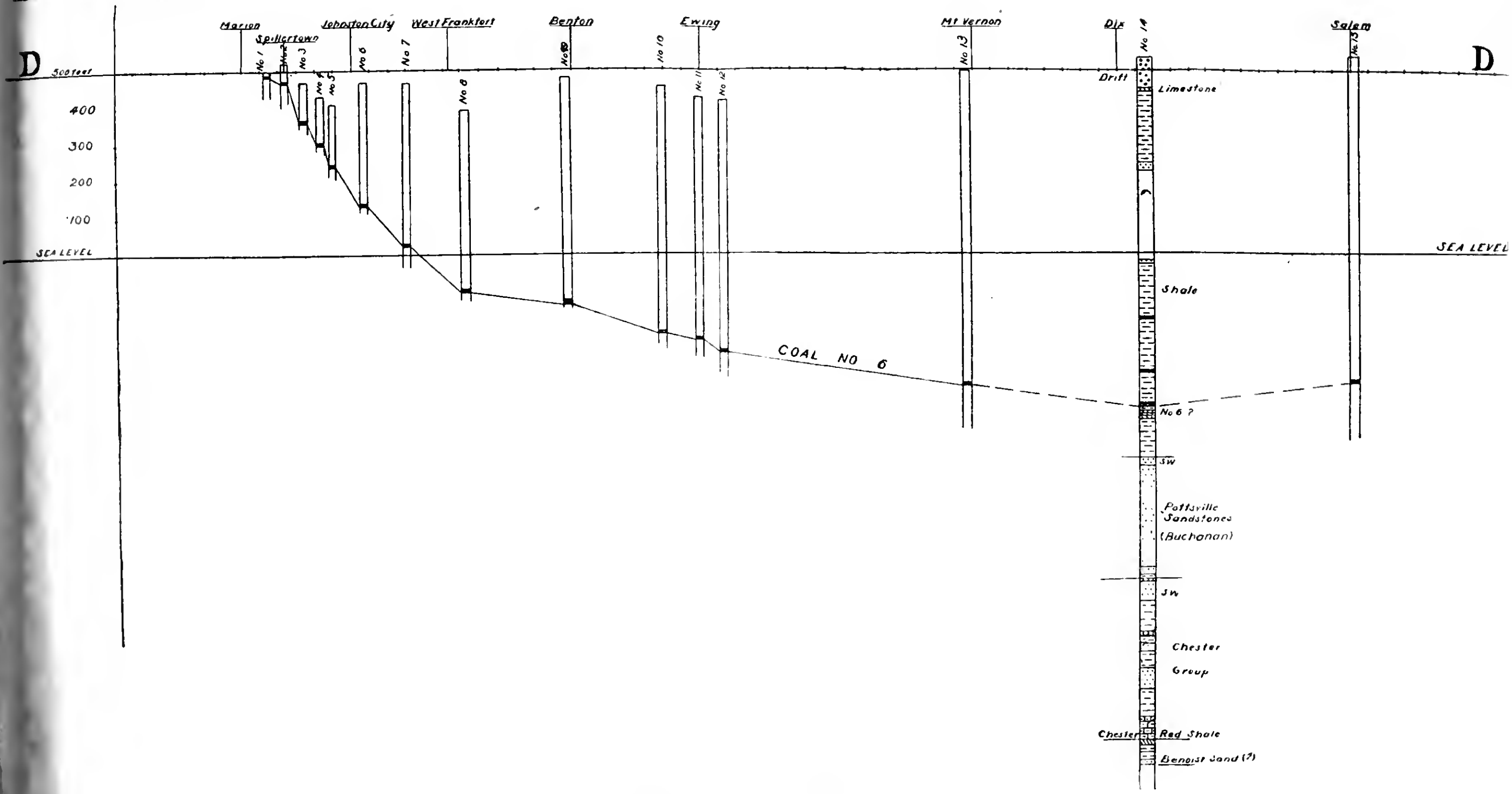


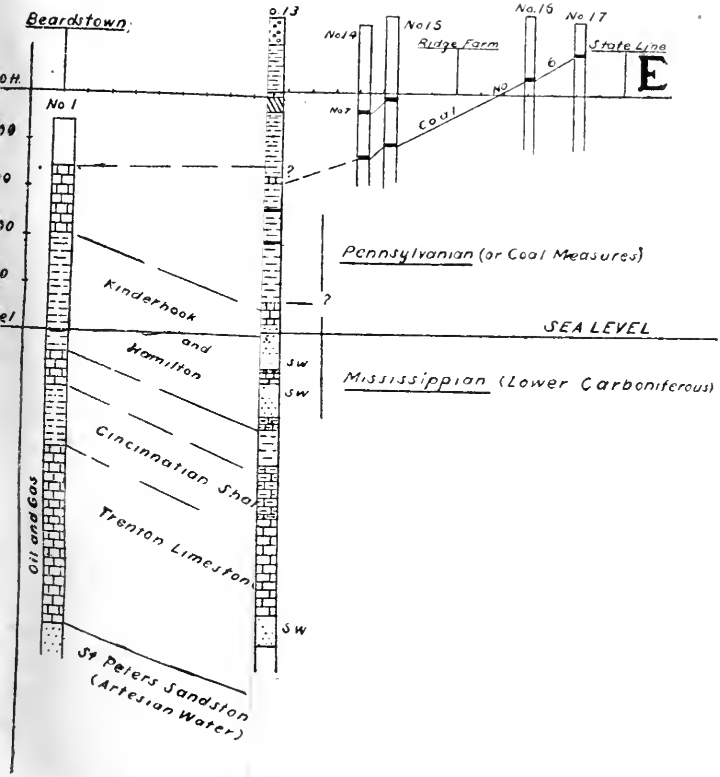
Plate 4.

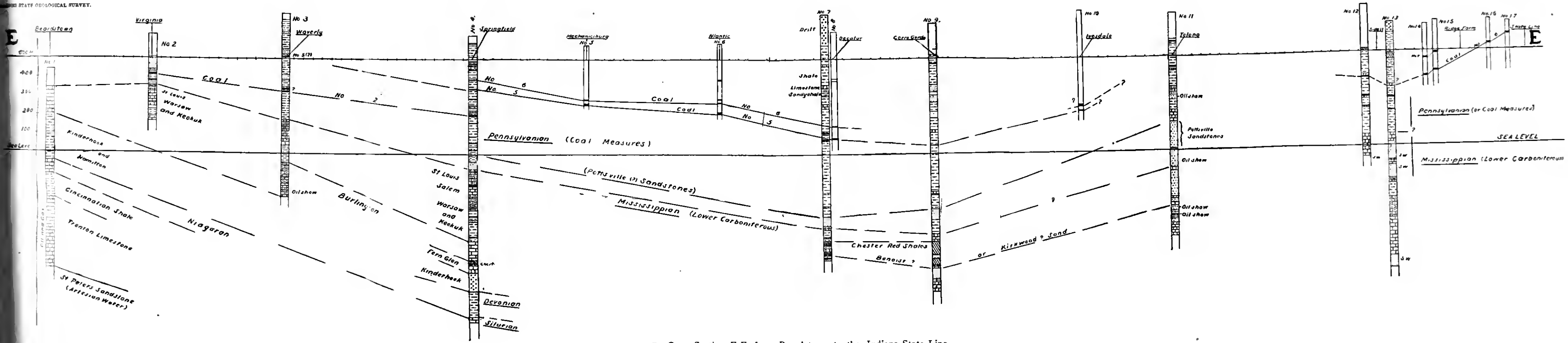
ILLINOIS STATE GEOLOGICAL SURVEY



4. Cross-section D-D, from Marion to Salem, Ill.

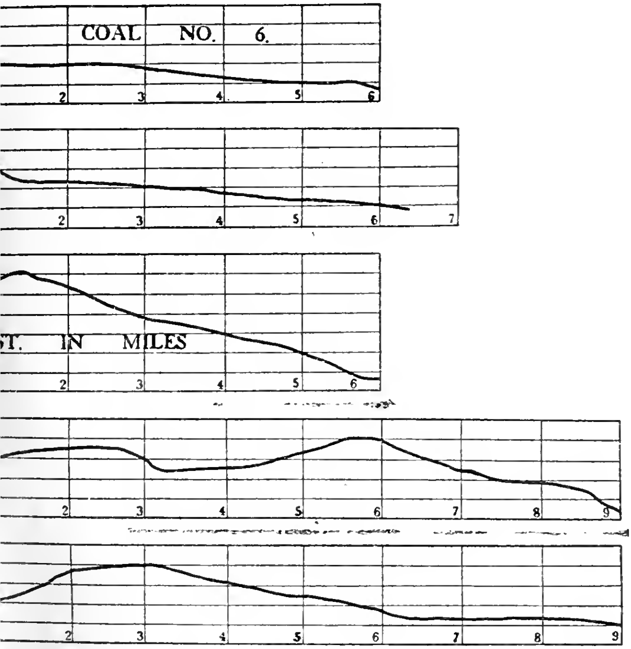
Plate 5.


Beardstown
No 1
Oil and Gas
Kinderhook and Hamilton
Cincinnatian Shal
Trenton Limeston
St Peters Sandston (Artesian Water)
o.13
No 14
No 15
Ridge Farm
No.16
No 17
State Line
E
No 7
Coal
No 6
?
Pennsylvanian (or Coal Measures)
SEA LEVEL
Mississippian (Lower Carboniferous)
SW
SW
SW



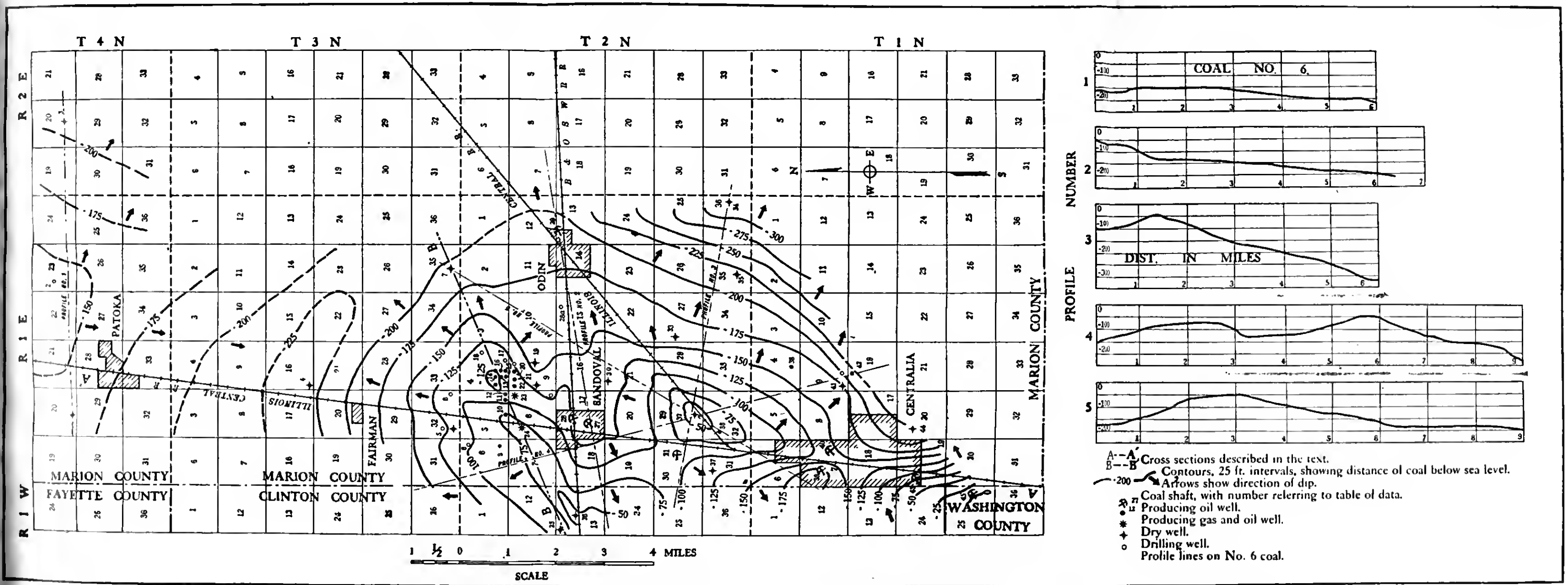
5. Cross-Section E-E, from Beardstown to the Indiana State Line.

Plate 6.



Cross sections described in the text.
Contours, 25 ft. intervals, showing distance of coal below sea level.
Arrows show direction of dip.
Coal shaft, with number referring to table of data.
Producing oil well.
Producing gas and oil well.
Dry well.
Drilling well.
Profile lines on No. 6 coal.

Plate 6.



6. A coal-contour map showing geologic structure and development in the Marion county oil fields.

Removal of salt water and steaming oil.—Salt water, which often accompanies the oil into the tanks, is drawn off at the bottom either by a bung-hole or by a siphon. The oil often has a yellowish color, caused by the suspension of sulphur. As this interferes with refining, the sulphur and other impurities are precipitated by steaming for three hours in a 250-barrel tank. The sediment is piped away from the bottom of the tank by gravity to a shallow pit at some distance from the buildings, where it is burned. A recent investigation by federal officials has put a stop to running waste oil into streams. Formerly, fish were killed and water supplies contaminated in this way. Fire losses were increased by saturating the foliage with oil along streams during high water.

The Approximate Cost of Oil Wells.

The following table presents the approximate cost of the first wells in the various Illinois pools:

				——Lawrence County—			
	Clark County.	Crawford County.	Bridgeport.	Buchanan.	Kirkwood.	Tracy.	McClosky.
Rig	....	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500
Drilling	$ 360	800	875	1,750	2,200	2,600	2,800
Drive-pipe	80	90	90	800	550	1,200	1,200
Casing	250	650	700	1,440	1,550	2,000	2,500
Shooting	90	90	90	100	100	100	100
Tubing and pumping outfit	150	150	150	200	215	250	250
Power and boiler-house equipment	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Tanks and sheds	250	250	250	250	250	250	250
Belting and lead lines	100	100	100	100	100	100	100
Incidentals	100	100	100	100	100	100	100
Totals	$2,580	$3,930	$4,055	$6,440	$7,765	$8,300	$9,000

The second and succeeding wells cost less by about $1,500.00 in Clark county, $1,850.00 in Crawford county, $1,900.00 for the Bridgeport pool, $2,600.00 for the Buchanan pool, $3,000.00 for the Kirkwood pool, $3,500.00 for the Tracy pool, and $4,000.00 for the McClosky pool. The rig, drive-pipe, a portion of the casing, tanks and power- and boiler-house equipment serve for several wells. The general cost of drive-pipe, casing, tubing and rodding is as follows:

	Diameter. Inches.	Cost. per foot.
Drive-pipe	16	$3.25
Casing (No. 50)	12½	2.15
Do. (St'd.)	12½	1.24
Do.	10	1.09
Do.	8¼	0.728
Do.	6⅝	0.5195
Do.	$5\frac{3}{16}$	0.407
Tubing	2	0.12
Oil line	2	0.098
Gas line	2	0.885
Sucker-rods	⅝	*4.04
Pull-rods	⅝	*3.57

*Per hundred feet.

Cost of operating a lease.—The minimum cost of operating a lease averages about $130.00 per month, allowing $60.00 as salary to the pumper, $40.00 for fuel, and $30.00 for teaming and supplies. It has been found profitable, therefore, to pump 3 or 4 wells of 5-barrel capacity. The monthly output from four 5-barrel wells, after deducting a royalty of one-sixth, is 500 barrels. At the current price of 60c per barrel, the income is as follows:

500 barrels at 60c	$300.00
Cost of operating	130.00
Net income	$170.00

The net income from ten 5-barrel wells or five 10-barrel wells would be about $615.00 per month.

Investments in Oil Properties.

Investments in oil properties fall naturally into two classes—those in the *wild-cat*, or unproven territory, and those in developed fields. One deals with chance and the other is largely a definite business venture.

An investment in a wild-cat scheme is at all times uncertain, because there is no assurance of finding oil. Wild-cat work is necessary for the development of any oil territory, but it should be left, if possible, to those large companies which have a reserve fund for such purposes. They often drill several wells before oil is found or the venture abandoned.

Since the Illinois fields were discovered, many men wishing to invest have found that the field was completely leased and that the only opportunity was to buy partially or wholly developed tracts. Even this was difficult because of enormous values and the scarcity of stocks of organized and prosperous companies. In the last two years the transfer of both developed and undeveloped leases has been common. The sale of properties is usually based on estimates of the remaining quantity of oil per acre per well. Some leases have yielded as high as 1,000,000 barrels per 20 acres, but others that looked favorable have yielded only 500 barrels per acre. The acreage drawn on by each well is dependent on the thickness and porosity of the sand, the area of the pool, and the distances to neighboring wells.

The Ohio Oil Company has been the most active purchaser of producing properties in Illinois. It recently bought out several large companies. Its total holdings are probably more than 70% of the total development. This company buys more than 90% of the oil of the state. How much of the production comes from its own leases is not known, but certainly it is not less than half.

Buying, Transporting and Storing Oil.

Buying Oil.—When the oil is steamed and ready to be sold, the power man notifies the Ohio Oil Company's gager, who determines the quality and quantity of oil on each lease. A duplicate report is signed by the gager and the lease man, and each retains a copy. The gager sends his to Marshall, Ill., where the company issues checks to the operator and the land-owner. In all reports 3% of the gaged oil is deducted for leakage and sediment and for evaporation, which goes on continually until the oil reaches the refinery.

Transporting the oil.—The Ohio Oil Company now has an extensive system of gravity pipe-lines for collecting oil from the entire field. It is constructed according to detailed surveys of each lease and of all stream courses through or near the field. This system displaced the old donkey pump that was formerly required on each lease. The efficiency is twice as great and the cost is one-third as much as before. The cost of transfer by the gravity system is borne by the Ohio Oil Company. The oil, after being gaged, is turned into the lines and flows to a central sub-station, where it is caught and pumped to the head station at Martinsville, Ill. Four sub-stations are maintained as follows: On the Ackman farm at the extreme southern end of the fields; at Bridgeport, Lawrence county; at Stoy, Crawford county, and at Martinsville, Clark county. Each controls the area north of it to the next station. From the head station at Martinsville the oil is pumped through one 12-in. and two 8-in. lines across Indiana and Ohio to Eastern refineries, and through one 8-in. line to Alton, Ill. The inter-state pipe-lines are pumped in relays, with sub-stations at Jamestown and Montpelier, Ind., and at Lima, Ohio. Oil is pumped at about 600 pounds pressure in the lines.

Storing the oil.—The production of the Illinois fields so far exceeds the capacity of pipe-lines that storage tanks have been established. Permanent tank farms are maintained at Martinsville, Stoy and Bridgeport. The sub-stations discharge the surplus oil to these tanks, where it lies until it can be pumped to the refineries. The Ohio Oil Company has over 500 storage tanks which hold about 35,000 barrels each. The cost of each tank, including the circular dike for catching the oil in case the tank bursts or catches fire, is about $9,000.00. The tanks are made of riveted steel plate, measuring ½ in. thick at the bottom and on the floor, and $\frac{3}{16}$ in. thick at the top. They are 95 feet in diameter and 28 feet 7½ in. high. The floor space is 7,200 square feet. The total investment in tank-farms and equipment is over $6,000,000.00. Other large companies maintain tanks, but they are scattered singly over the field.

Lightning has occasioned heavy losses on tank-farms. At least one dozen tanks have been destroyed in the last two years. Lightning pierces the tanks easily and sets fire to the gases and oils. In a short time the top of the tank drops in and the flames send up dense, black, curling smoke, which presents a most unusual and startling spectacle. It requires about 24 hours for the whole liquid to boil over the sides of the tank, and 50 hours for the fire to burn out. At the time of boiling the smoke and the danger are greatest. The Ohio Oil Company always rushes a large force of men to the scene and takes every precaution to minimize the loss by strengthening the dikes and removing inflammable materials. The nearest pumping station connects with the burning tank and draws out as much oil as possible with safety, usually about half the amount in the tank. The loss by fire of a tank full of oil is about $20,000.00.

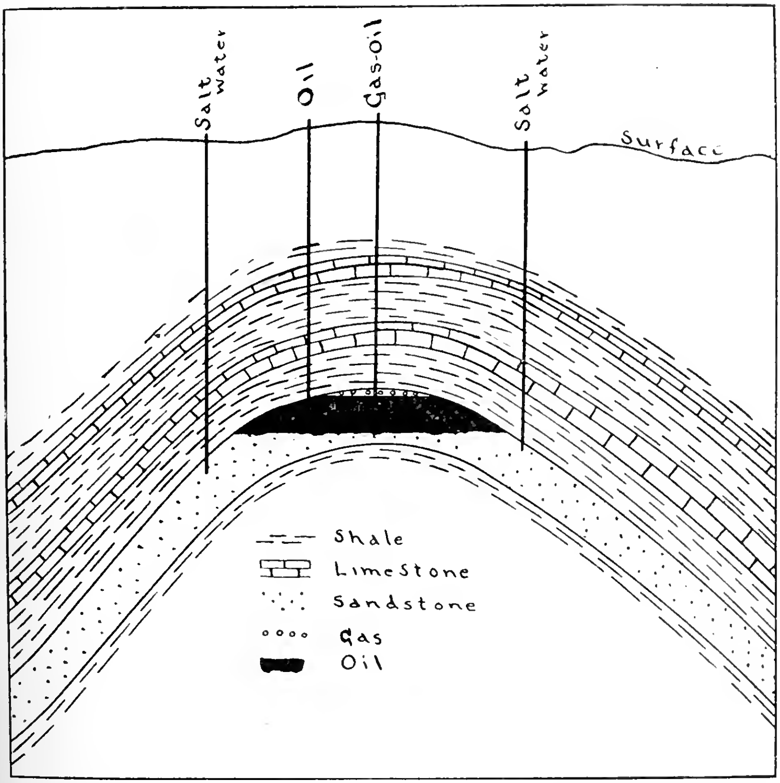
DISCUSSION.

President Chamberlain: The paper is now open for discussion. Professor DeWolf, the State Geologist in charge of the Illinois State Geological Survey, is with us this evening, and I will ask him to open the discussion.

Frank W. DeWolf, M. W. S. E.: I do not care to say very much this evening; I have had altogether too much fun and worry helping Mr. Blatchley get this paper together. I say worry, because the work that we have been doing has been carried on under a good many difficulties. At the time the Survey was created in 1905 there was no oil production in this state. Those who devised the plan for appropriations to the Survey had in mind, therefore, only the ordinary demands of the coal industry, clay industry, and some others which are always with us,—and they made our funds adequate for the needs at that time. Almost at the same moment, however, this big oil boom struck us, and has deluged us with letters of inquiry about the possibilities of getting oil on John Jones's farm, and Sam Brown's farm. It has sometimes been quite embarrassing to try to answer those questions wisely. We have had to squeeze out the fund from some of our other investigations so as to carry forward the oil work. Mr. Blatchley has had charge of it for three years now, and has given his whole time to it.

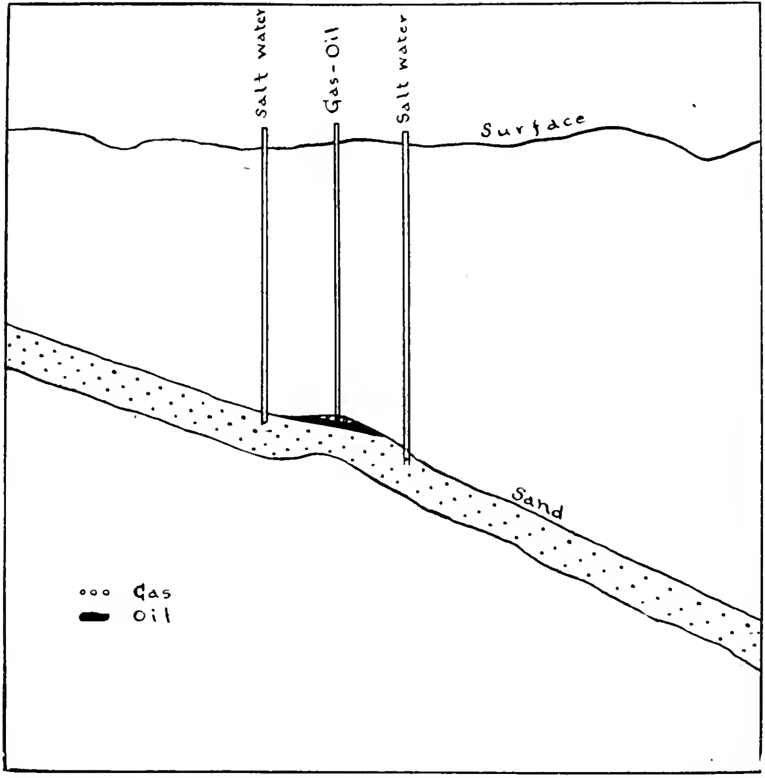
Unfortunately, the oil producers for the most part are a nomadic group of people, who are with us today and gone next week. The farmer himself gets one-eighth of the production; and it is only to that extent that the state directly profits by this oil production. Seven-eighths of it goes to operators from outside regions. While much of the money is spent in Illinois, it is hard to get any united organization to express an appreciation for this oil work and so to help us get the funds with which to carry it on. The operators are not with us long enough to feel any great interest in the scientific work. The present fields will perhaps be drained in the course of ten years; it will all be over. Nevertheless, it seems only right that we should try to do something to help out the production and to check the drilling in undesirable territory.

Theories of oil and gas distribution have been pretty well worked out in the East, particularly in West Virginia and Pennsylvania, where the rock structures are very strong. The anticlinal theory has seemed to meet the condition in those fields and has been a great help in stopping unnecessary and unwarranted drilling in poor territory. In Illinois, conditions are not so favorable for geological work, because the rocks are mostly covered up, as Mr. Blatchley has said. It is only by collecting drill records that we can determine the position of folds, and even then, while the probabilities are that these folded regions will yield oil, the dips are so gentle as to be less important than variations in rock porosity. Thus it is altogether possible that a hole might be put down on the crest of one of our most favorable anticlines, but that it would find the sand a little too dense to contain the oil.



Sketch of the accumulation of oil and gas in an anticlinal fold. This is the condition in the main Illinois fields.

There is one other condition to which attention has been called regarding the anticlinal theory; that is, that there is an intimate relation between the distribution of oil on the anticlines and the amount of salt water in the sands. I will try to make that clear by asking you to picture the condition at the time those sands were deposited under the sea. We know they are marine beds; that they were once loose sands, which were later cemented together. At that time the sands were full of sea water and contained more or less vegetable and animal matter which later gave rise to oil. When the rocks were lifted and tilted and folded, there was a natural tendency for water in those sands to run down hill into the basins,—into the deeper parts of the structure. As a result the sands, in some places along the tops of the anticlines, contain absolutely no water. They are dry sands, in regard to water. As Mr. Blatchley has said, any oil present will be found floating on that water. But if the conditions have been right for the water to drain out of the anticline down into the lower parts of the structure, the oil will be found



Sketch of the accumulation of oil and gas along a bench or structural "terrace" on the flanks of a basin. This is the condition of the Sandoval field.

down in the basins on the water and not in the anticline proper. The anticlinal theory, then, does not mean that the anticlines are always the most promising areas for drilling, although that was the first conception of it, and that was the condition which gave its name to the hypothesis. It is necessary to have data on the amount of water in the sands before we can predict with any degree of certainty as to where the oil will be found. There are many pools which produce oil from synclinal basins or troughs, containing little or no water. Where the sand is partly filled with water the oil will lie, perhaps, part way up the slope of the anticline. Where it is entirely filled with water the tendency is for the oil to be right on the crest of the anticline. As I said before, these theories are always subject to modification, depending upon the porosity of the sand. If the sand is not porous enough to permit free circulation and normal arrangement of these substances, all theories will fail.

President Chamberlain: We have with us this evening the head of the Geologic Department of Northwestern University, Professor Grant. We shall be glad to hear from him, if he has anything to say.

U. S. Grant: I think Mr. Blatchley and Mr. DeWolf have been too modest in not stating what a large amount of work has been done for the preparation of this paper. They have been at this work for a long time, ever since the oil boom started, and their results show that a great amount of very careful work has been done in collecting and compiling the logs of so many oil wells, but it means much more work and a higher degree of skill when they come to interpret the logs. When Mr. Blatchley puts a well record before us on the screen and explains how it goes, it all seems very simple and easy, but any one who has tried to interpret well records, especially the apparently conflicting and varying records of wells sunk in the Pennsylvanian rocks, knows that the interpretation is no simple matter; it takes much skill and labor.

I think these gentlemen have also been too modest in stating the high value of their work in mapping out these oil fields and especially in indicating definite areas where conditions are favorable for oil accumulation. The facts which have been presented in this paper should save a great amount of expense in useless drilling by concentrating drilling in certain favorable areas. While I think Mr. Blatchley would not in any way claim that oil will be found in each of these structural terraces or small anticlines, still he does claim that these are favorable places for drilling. Mr. DeWolf said he had been embarrassed in the past in answering letters about oil on John Jones's farm. I imagine he may later be still more embarrassed by letters from people who have drilled in the areas indicated as favorable and found no oil!

It has been suggested that there may be oil fields further north along the La Salle anticline, and it might be added that in the lead and zinc district in the northwestern part of the state there is a stratum of a few inches or a few feet in thickness which is locally known as the oil rock. This stratum is rich in organic matter, so much so that a splinter of it will sometimes burn when ignited by a match; and from this rock it is possible to extract both oil and gas. In this district there has been gentle folding and so there are anticlinal areas, but erosion has gone so far that the impervious layers above the oil rock have been extensively removed; and no promising occurrence of oil derived from this oil rock by natural distillation has been reported.

In the northeastern part of the state the oil rock stratum seems to be lacking, but there is a long monocline in which the rocks dip very gently towards Lake Michigan. It is possible that terraces may occur on this monocline and so furnish favorable places for the accumulation of oil. But as far as our present knowledge goes the underlying strata are not productive of large quantities of oil. About 1864 a well was drilled for oil in Chicago, with unfavorable results. The Niagara limestone about Chicago contains some petroleum and asphalt, especially at Stony Island, which "island" is anticlinal in structure.

H. A. Wheeler: I wish to congratulate you on the presentation, in very concise form, of one of the best papers I have read on the Illinois oil industry. I came up from St. Louis mainly for the purpose of hearing it, as it is the most valuable contribution I have seen on this very important oil field.

The Survey seems to have been impressed, as the oil men have, with keeping this matter quiet. It is simply astounding that Illinois, which seven years ago did not produce a barrel of oil, has made the most brilliant record in the history of the oil industry, yet the public have been most studiously kept in ignorance of it. Oil operators have quietly slipped in from Ohio and Pennsylvania and absorbed the huge profits, while capitalists of Chicago and St. Louis are almost in total ignorance of the field; yet no oil field has ever been so profitable, or reached such a large production in such a short period as this Illinois field. While Oklahoma and California are today producing more oil, it took Oklahoma some eighteen years to attain it, and it has taken California fifty years to develop it to its present large output, while Illinois is only six years old!

I wish to disagree most emphatically with Mr. DeWolf that in ten years the Illinois oil industry will be a matter of past history. On the contrary, I do not look to see Illinois reach its maximum for many years. At least, that has been the history of all the other oil fields.

In Pennsylvania, where the oil industry was born sixty years ago, it took thirty-two years to reach its maximum, while in Indiana, where geology clearly pointed out where to do the drilling and it was the quickest to reach its maximum, it took fifteen years. It takes a large amount of time, as well as money, to open up a new oil field, and Illinois is not going to be an exception to this rule. The geology of Illinois is difficult to work out from the surface evidence, while the streams and coal mines give but little stratigraphic data from which to determine the anticlines. As the modest appropriation for the State Survey will not permit it to drill to obtain the necessary information, it will have to wait for the "wild catter" or pioneer oil men to furnish the evidence that will blaze the trail to a much larger number of structural deformations that are unknown at present.

To appreciate the commercial importance of the Illinois oil industry, the production last year was 35,000,000 barrels of oil that realized over $20,000,000. This was virgin money that had been sleeping for millions of years. What the production will be ten or twenty years hence, it is impossible to predict, but all past experience shows that it will be much larger, as the probabilities are that there are more pools undiscovered and untouched than are producing today. It is the eastern side of the state that has made the glorious record, as the western side, which geologically is equally as favorable, has only just begun at the Sandoval pool.

I would ask Mr. Blatchley what he finds the average cost of production of a barrel of oil put into the tanks at the wells. The data he gives indicates that the cost of the oil put into the tanks, after paying all field expenses, was about 26c a barrel, which is highly misleading. While his figures show that even a small lease is profitable, it is not representative, as few leases are so small, and it gives an erroneous idea of the cost of production. The cost of production varies greatly in the different districts, as well as on different leases in the same pool, according to the size of the wells and many other local conditions, but the range of 6c to 15c per barrel usually covers the cost of the oil in the tanks ready for the market.

A. Bement, M. W. S. E.: This paper interests me very much. I think it a remarkable piece of work. It especially interests me on account of its industrial bearing and significance, and I think we should get a lesson from it in connection with the geological survey work in general. What Mr. Wheeler says is very largely true, the geologist should precede the industrial man, but he too often follows him, and we lose much by it. I think if we could realize, and our members of the legislature could realize, that it is important and necessary for the scientific man to precede the practical man, it would result in a large financial gain to the community.

I am very glad to see that so much work has been done with borings; that so much data have been put together from records of borings in this state. As has been stated, it is a very large piece of work, not only to collect the data, but to analyze it. This reminds me of something I said when we discussed this matter of the geological survey some years ago, shortly before the law was passed creating the survey. My opinion was that we could do a great deal with logs of borings, and I am very glad to see the fact demonstrated.

Regarding a remark from Mr. DeWolf. I would like to speak of the financial gain realized from the oil business by the state. While it is true that the farmer gets only an eighth of the production, a very large sum of money is spent for the plant and for employes who are permanently engaged; in addition there are a large number of people, temporarily engaged, who reside in the state a considerable length of time and spend a good deal of money here. So I think we, as a state, gain more from oil production than we sometimes realize.

I remember going to Crawford and Clark counties to report on the prospect of oil when some of the first wells had been put down, but by inexperienced people without result. It seemed to me that there was oil to be found and I so reported to the client. Whether anything ever came of it, I do not know. But it is remarkable that the Illinois development should have been delayed so long, when in Clark County oil seeped for years from a small spring and a town near by took its name from that fact. It would seem that it required the services of those men who had had experience in the eastern fields, and had learned the oil game,—who knew how to take a chance and how to follow it up. These men came out from the East and visited Ohio, then Indiana, and when they were through with that state, they went to Illinois, without any definite idea as to what they were going to do; but they looked around and followed up the prospect until it has resulted in this enormous development.

President Chamberlain: I was impressed with what Mr. Wheeler said in regard to the fact that few people in the state of Illinois realized the importance of the oil production of this state. I must confess that I was greatly surprised, in reading Mr. Blatchley's paper, to learn that Illinois stood as high as it does in oil production, and I presume there are very few people who are not interested in the oil business or in engineering or geological matters who are at all familiar with the subject. We have not generally regarded Illinois as an oil-producing state.

If there is no further discussion, I will ask Mr. Blatchley to close the discussion.

CLOSURE.

The Author: I want to say again that the object of this work—this new work—is merely to lead the prospectors to the localities where we think that the conditions are favorable for the accumulation of oil. We do not want it understood that we say there is oil at any such place, because no man is able to tell this. The drilling-bit alone is able to find the oil. We feel that we can save the prospectors a great deal of money by keeping them away from basins that are seemingly full of salt water.

Professor Grant spoke about the northern part of the state being somewhat prospective. In the new bulletin just issued I have brought out the fact that there is a chance for oil in the pre-carboniferous rocks in the northern-central portion of the state. The area through Woodford and McLean counties and in and around Beardstown looks very good indeed for prospective work. Dr. Udden, of Rock Island, who does a great deal of work for the Survey, has given me a list of the towns where the Trenton may probably be found about 1,000 feet deep, and they are presented in this forthcoming bulletin.

I would like to say a word at this point in regard to the great work that has been done by the Ohio Oil Company in this state. They have developed systems that are not present in other fields. For example, their gravity system of oil transportation, taking advantage of the creeks and the streams and allowing the oil to flow by weight and thereby saving a great expense, is one of the engineering feats of the new field. Mr. E. C. Bolton, chief engineer of the company, developed this system and did it most thoroughly. He surveyed every lease and these data, in themselves, are valuable from a topographical point of view.

Another point was brought out about the life of the various pools or production in the state. I think the shallow fields are almost abandoned at the present time, or are very rapidly becoming so, because the oil was found at the shallow depth, the field was drilled rapidly, and the drain has been great. Coming farther south to Crawford County, the field is somewhat deeper and its life will be extended several years in advance of the Clark County field. The deeper fields of Lawrence County will, as I see it, have quite a long life and they should compare favorably with the Pennsylvanian fields, of thirty years or more of activity, because the producing sands are six or seven in number and are very prolific. The western part of the state holds a great deal of promise and I feel sure that there are many pools untapped. The area has by no means been tested sufficiently, and the fact that the Sandoval field at the present time is small and isolated would lead to the conclusion that there should be similar fields or pools along these structural benches.

In answer to Mr. Wheeler's inquiry about the cost of wells, I have made an estimate of the cost of producing, giving the cost of the initial and the second wells. I admit that the choosing of the low-yield wells was merely an example of what could be done with small wells. I consider that five barrels is the lowest favorable yield in the state and that this can be carried on profitably; but, of course, the average is much greater than that. In some places blocks of twenty acres have been found to yield a million barrels of oil and others that seemed promising have only yielded 500 barrels. There is great variation of production in the different portions of the field and also in porosity of the sands.

The oil men are, I think, just beginning to take cognizance of the work, and we are looking forward to a great deal of help from them.

I would like to say at this point that if any member of the Western Society of Engineers can secure records of any new wells, he would do us a great favor by referring the same to us or else furnish information about securing those records, because, as you have seen, we have to depend almost wholly upon well-records for our studies, and those studies, I think, will be continuous as long as there is oil work in the state.

ELECTROLYTIC CORROSION OF IRON IN CONCRETE.

Charles F. Burgess*, M. W. S. E.

Presented February 22, 1911.

This paper has for its purpose the presentation of results of experimental work dealing with a study of the extent to which concrete may act as a protective agent against the electrolytic corrosion of iron imbedded in it.

Mr. A. A. Knudson, *Transactions American Institute of Electrical Engineers*, March, 1907, appears to be among the first to have conducted investigations of the electrolytic corrosion of iron in concrete. His conclusions were somewhat sweeping in that they contained a statement that where but a small current passes from iron to concrete or masonry there will be a corrosion of the metal and disintegration of the concrete or masonry. He called attention to the calamities which may result from this fact; but the justice of his conclusions were questioned by those who took part in the discussion of his paper. Other contributions on this same subject have been offered by Professor A. S. Langsdorf, *Journal of the Association of Engineering Societies*, Vol. 42, 1909, and by Mr. W. J. Nicholas, *Engineering News*, Vol. 60, 1908. These papers were in a measure confirmatory of the views offered by Mr. Knudson.

The principal basis of objection to the conclusions of this first paper appear to be that the experiments were not illustrative of what may occur in practice, in that a constant current of 0.1 ampere was passed through a concrete block from an imbedded iron pipe, the voltage being raised continually to maintain the current at a constant value. This required in some cases a high voltage and liberation of heat, which resulted in a cracking and softening of the concrete within a 30-day period of exposure to the action of the current.

In view of the fact that reinforced concrete has become one of the most important structural materials, it is reasonable that the charge made against this material, that a very small electric current will result in its destruction, should be accepted with caution. The importance of the question merits far more attention than has been given to it, and in offering the results of further study it is appreciated that there is still much analytical work to be done before an exact quantitative idea may be had of the depreciation caused by electrolytic corrosion.

In a publication of the Carnegie Library of Pittsburg, entitled "Metal Corrosion and Protection" there is an extensive

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bibliography, a portion of which deals with literature on cement and concrete as a protection against corrosion, there being forty-eight articles and papers included under this division. Comparatively few of these, however, relate to the electrolysis factor.

During the past three years there have been carried on at the Chemical Engineering Laboratories of the University of Wisconsin, two series of tests on the quantitative effect of electrolysis on iron in concrete, and some of the results of this work have been drawn upon in presenting this report. More detailed descriptions are given in theses prepared by F. F. Farnham, in 1909, and A. B. Chadwick, Jr., in 1910.

It has become a generally appreciated fact that concrete absorbs water and aqueous solutions and thereby becomes electrolytically conductive. The conductivity varies through a wide range, depending upon the nature of the concrete itself as to physical and chemical composition, and to the composition of the impregnating solutions. From various sources of information it appears that the resistance of cement and concrete may be anywhere from 30 ohms to several thousand ohms per foot cube, values which are comparable to the specific resistance of earth materials.

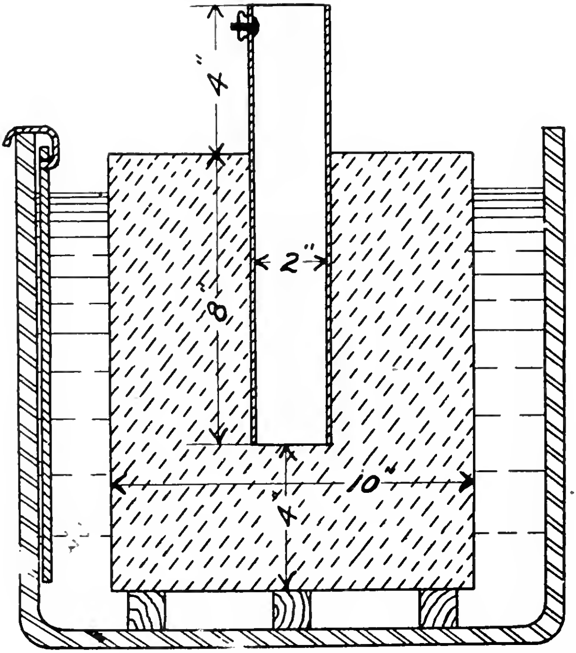

Fig. 1—Dimensions of Specimens Used in First Set of Tests.

In carrying out the experiments to be described the purpose was to employ conditions typical of those which may be met with in actual practice. A constantly applied pressure of 8 volts was employed as being a value which, although somewhat high, is occasionally encountered and even exceeded in existing structures. Although this value is higher than the average, it was necessary to choose such pressure as would give distinct results in reasonable time. Two sets of tests were made, the first covering a period of 180 days and employing concrete moistened with water, and the second covering a period of 64 days, using salt solutions. The dimensions of specimens used in the first set of tests are illustrated in Fig. 1, and in the second set of tests by Fig. 2.

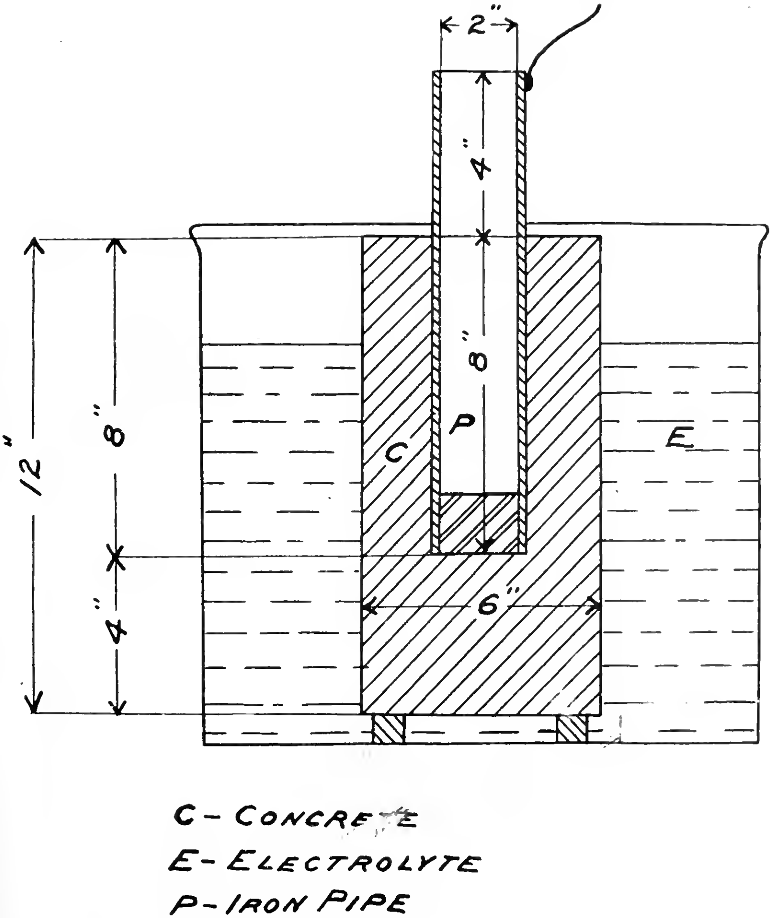

Fig. 2—Dimensions of Specimens Used in Second Set of Tests.

The first ten test specimens were made of various brands of cement and in various mixtures. In some cases the cement was poured into the mold moist and in others wet. The imbedded iron consisted of a 2 in. wrought iron pipe which had been previously washed carefully, the lower end being closed by a paraffined wooden block to exclude moisture. Specimens were set in a mold for 48 hours, at the end of which time they were put into earthen jars containing lake water, where they remained for 12 days before electrical pressure was applied. The cathode consisted of an iron plate hung from the side of the jar. The cells were electrically connected in parallel, Fig. 3, current being supplied by storage cells through a rheostat by which a fairly constant pressure value was maintained throughout the test. By taking frequent measurements of current, applied pressure, and polarization pressures, the principal records of the tests were obtained. The summary for this series is given in Table 1. The loss in weight was determined by preliminary weighing, and another weighing at the end of the test after the samples had been scratch-brushed to free them from adhering rust. By integration of the current values the number of ampere hours which flowed from each of the specimens was obtained. Assuming 1.05 grams per ampere hour as the electrochemical equivalent of iron, the theoretical corrosive action of the current was obtained. and by comparison of this value with that actually obtained by loss of weight, the figures in the column headed "current efficiency" were calculated.

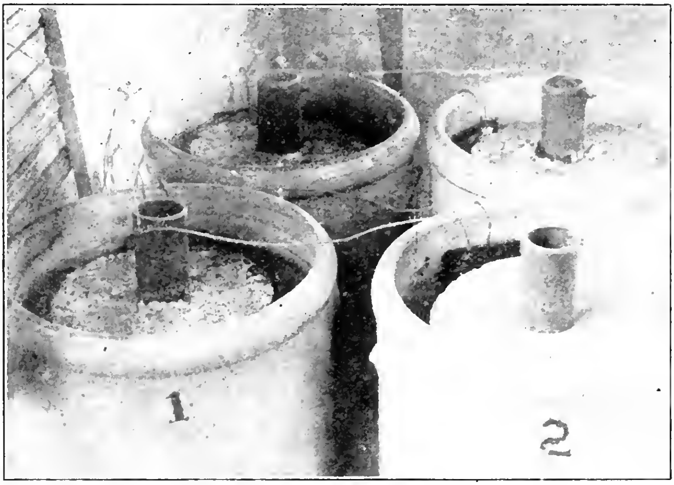

Fig. 3—Cells Electrically Connected in Parallel.

In view of some of the previous publications it was a matter of some surprise that current efficiencies were found to be of low value. These indicate that concrete may have some protective action other than that offered by its questionable insulating property.

In this first series of tests there was little evidence of cracking or softening of the cement. Samples employing neat cement showed some slight cracking at the beginning of the test, but this was evidently apart from the influence of the electric current.

The examination of the pipes after cleaning at the end of the test showed that corrosion had taken place in the form of pitting, Fig. 4, the pitting being the more marked at the top.

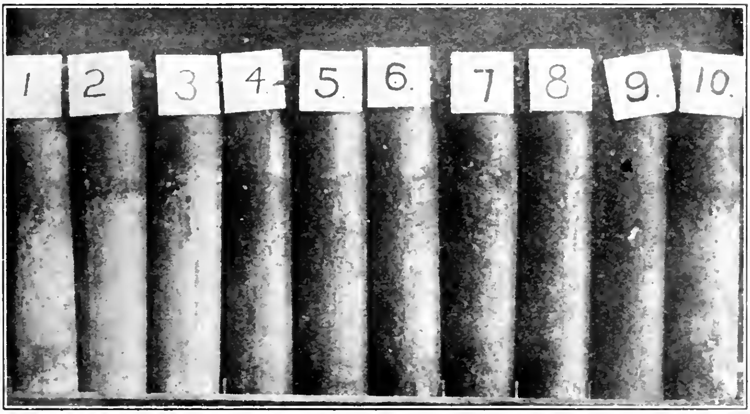

Fig. 4—Corrosion in Form of Pitting.

That the observed rusting and pitting was due to electrolytic action was evident by comparison with a check sample, from which no current was passed and which at the end of the test was found to be in a bright uncorroded condition. The low current efficiency of corrosion indicates that the current under these conditions expends itself in the liberation of anode products other than the formation of iron compounds. This is evidenced further by the frothing and the liberation of gas which appeared at the top of the concrete block near the iron anode.

The second series of tests was undertaken to determine in what measure the addition of salt to the water would influence the current efficiency of corrosion. For this purpose 3% salt solution was chosen as being typical of the conductivity of sea water and possibly of solutions which may be found under soil conditions.

The specimens were similar to those of the first series with the exception that the cement blocks were 6 in. instead of 8 in. in diameter, thus leaving a wall of cement about 2 in. instead of 3 in. for the current to pass through. This offered a lower electrolytic resistance, and therefore a means of decreasing the duration of the tests.

Concrete was taken from a concrete mixer handling material in proportion of 2 parts of cement, 4 of sand, and 6 of crushed stone. Two mixes were employed, one using Marquette cement and one the Medusa brand. This concrete was tamped around the iron pipes as in the previous tests, and the resultant blocks allowed to set for 28 days before being placed in the electrolyte in stoneware jars.

The 3% sodium chloride solution was used for seven of the specimens, ordinary lake water being employed for the other three, as a means of comparing this series with the former one.

The measurements of current, pressure, and polarization were taken almost daily for 64 days, the duration of the run. The pressure applied to each of the specimens was kept close to eight volts. The electrolyte was kept at constant level by occasional addition of water.

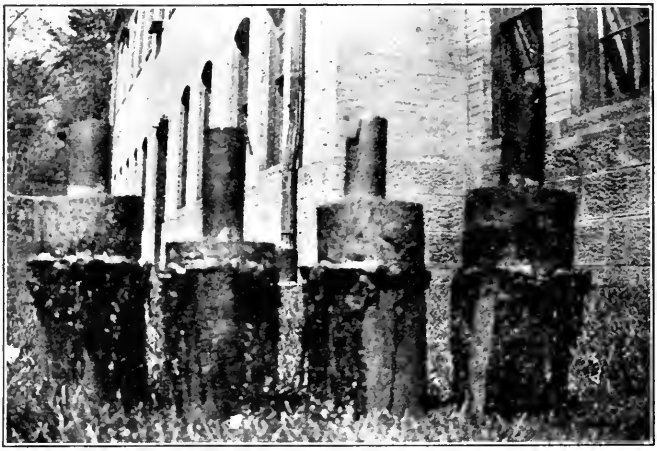

Fig. 5—Appearance of Blocks from Use of Salt Solution.

A ferric hydrate precipitate formed in all of the salt solutions; this crept up the surface of the exposed concrete and gave a rusty appearance to it. At the termination of the test the concrete blocks were removed from the solutions. Those from the salt solution had large and irregular adhering deposits of iron hydrate; these deposits apparently started at the surface of the solution and grew downward in large stalactitic formations.

Fig. 5 shows the appearance of the blocks from the use of salt solution, and Fig. 6 from the use of lake water. The blocks were broken by a hammer. In no case was the concrete softened, the only defects being the cracking noticed in blocks 11, 12, 13 and 14. The concrete had little rust or iron deposit in it except along the cracked surfaces. It is not certain that the cracking was caused by the electric current.

An examination of the pipes showed those exposed to salt water to have been corroded far more than were those of the previous test, or of those in lake water. The corrosion of the pipes started not at this surface level of the electrolyte but at the upper surface level of the concrete block. This is naturally the case on the basis that the solution works up into the concrete and renders it electrolytically conductive. The corrosion was found to be most marked at the locations of the cracks, the pipes having been entirely perforated at these places, but even in those specimens which had not developed defects in the concrete the corrosive pitting was very marked.

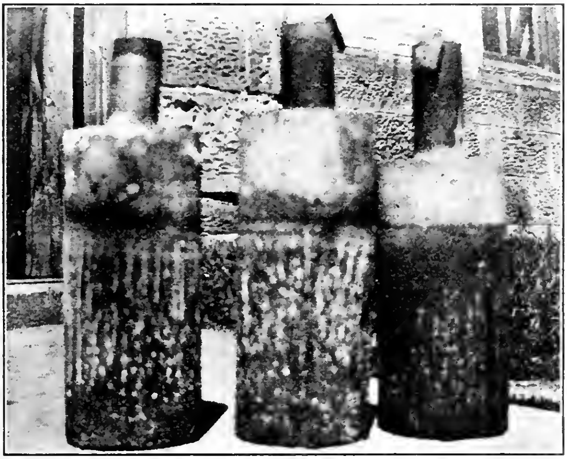

Fig. 6—Appearance of Blocks from Use of Lake Water.

Fig. 7 shows the appearance of the corroded pipes.

After brushing and cleaning the pipes they were weighed and the losses determined. By comparing these losses with the loss determined by averaging the current readings the percentage corrosion efficiency was determined.

Data concerning this test are given in Table 2. The deductions from this table are that the corrosion efficiency where salt is used in most cases is about 60%.

It appears from this table that there may be some relationship of polarization pressure to corrosive action, as those specimens showing greatest corrodibility by the current have the higher polarization pressures. This is contrary to what might be expected, on the supposition that low current efficiency means the setting free of products of decomposition of the electrolyte and the setting up thereby of higher polarization pressures

These tests show in a decisive manner the fact that salt in solution greatly increases the conductive power of concrete above that produced by ordinary water. They also show that the electrolytic corrosion of iron is thereby greatly enhanced by the presence of salt. There was no evidence, however, that the concrete itself undergoes any chemical deterioration by electrolysis. While some of the test samples cracked during the test, it is not believed that we have shown conclusively that this cracking is connected either directly or indirectly with the flow of current.

Table 3 is a compilation of data and deductions intended to get a quantitative idea of the corrosive action of the current. In the third column are given the average values of current flowing throughout the test on each of the specimens. The current is at a maximum at the beginning of the test and decreases to a more or less constant minimum value after a certain lapse of time. It was found that the minimum values had been reached during both of these two series of tests, and it is probable that these minimum values should be used rather than the average values where calculating what may happen under field conditions. These values of minimum current are therefore given in the fourth column. The average current of the tests is reduced to current per square foot of iron surface in column five, and the experimentally determined corrosion efficiencies in column six

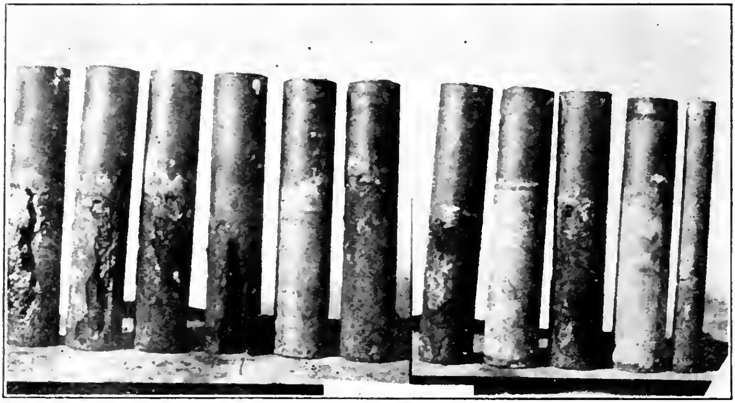

Fig. 7—Appearance of Corroded Pipe.

Using 20 lb. of iron per ampere year as the electrochemical equivalent of iron, the amount of iron to be corroded per year under the experimental conditions from each square foot of surface is given in column seven. Taking into account the minimum currents rather than the averages of the tests, gives column eight, which may be the really useful one for conveying a quantitative idea of the corrosion which may be encountered in practice.

A corrosion of 0.02 to 0.08 lb. of iron per square foot of iron per year is shown to be possible where concrete is subject to the action of ordinary water. This may or may not be a negligible depreciation factor, depending upon the massiveness and proportions of the encased iron. It must be borne in mind that the corrosion is not uniform, that pitting is the characteristic, and that should any cracks develop, the corrosion is concentrated at such places.

It is also seen in this column that the presence of a salt in the water increases the rate of corrosion one hundred times, due in part to the greater electrolytic conductivity but in much greater part to the increased corrosive efficiency of the current. While a 3% salt solution may give results typical of what may be expected from sea water, the seepage water of city streets is undoubtedly less harmful than the 3% salt solution. A quantitative investigation of the action of these and other solutions would be of importance as bearing on this question.

In interpreting the data above set forth, it must be borne in mind that an electrical pressure of eight volts has been assumed. This is higher than is generally found under actual conditions. Correction for lower pressures can be approximated by the application of Ohm's Law, taking into account a maximum polarization of from one to two volts.

Polarization pressure measurements were made throughout the conduct of these tests to determine, if possible, any relationship which might exist between corrosive efficiency and polarization pressures. No such relationship was established and it is not deemed essential to burden this paper with such data.

If, as shown in this paper, the possibility exists of removing 5 lb., 1 lb., or even 0.1 lb. of iron per year from a square foot of iron surface imbedded as reinforcement in concrete, it becomes a matter worthy of more attention than has been given to it in the past. It is true that comparatively few failures of structures have been attributed to electrolysis in the past, but we may not conclude from this that the time of reckoning with this factor will be indefinitely postponed.

Cement and concrete have been tried repeatedly as a protection to underground gas and water mains and services, but naturally with little beneficial results. There has been called to the attention of the writer the failure of concrete arches which is apparently attributed to electrolytic action, and we may naturally wonder how far this phenomenon may be responsible for some of the mysterious failures of concrete work which are recorded with some frequency and regularity.

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The question is certainly entitled to further investigative study. This should include determinations of conductivity of concrete as influenced by composition, by different electrolytes, by methods of mixing; also the determination of the corrosive efficiency of the current as influenced by the variety of conditions met with in practice. In addition to laboratory work of this sort there should be made field observations as to leakage currents and their influence on structures.

TABLE 1.

Specimen No.	Brand of Cement	Mixture Cement—Sand—Gravel	Condition of Mix.	Loss by Corrosion —Grams	Ampere Hours	Current Efficiency of Corrosion
1	Atlas	Neat	Moist	7.2	416	1.66%
2	Chicago A-A	Neat	Wet	3.4	86.4	3.89%
3	Universal	Neat	Wet	1.2	109	1.05%
4	Universal	1-3-6	Wet	6.6	145	4.36%
5	Chicago A-A	1-3-6	Wet	7.5	134	5.38%
6	Atlas	1-1	Moist	9.8	458	2 06%
7	Atlas	1-3	Wet	11.7	163	6.88%
8	Atlas	1-3-6	Wet	6.3	131	4.61%
9	Chicago A-A	1-3	Moist	8.5	288	2.84%
10	Universal	1-1	Moist	5.2	413	1.23%

TABLE 2.

Specimen No.	Brand of Cement	Electrolyte	Loss by Corrosion —Grams	Ampere Hours	Current Efficiency	Polarization 64th day
11	Medusa	3% NaCl	210	355	55%	1.90 volt
12	Medusa	“	247	295	80%	1.90 “
13	Medusa	“	105	248	40%	1.70 “
14	Medusa	“	203	294	66%	1.65 “
15	Marquette	“	178	246	69%	1.90 “
16	Marquette	“	113	174	62%	1.80 “
17	Marquette	“	192	268	69%	1.75 “
18	Medusa	Lake Water	0	29	0	1.20 “
19	Marquette	“	0	30	0	1.25 “
20	Marquette	“	1	31.3	3%	1.30 “

TABLE 3.

Specimen No.	Electrolyte	Average Current Amperes	Current at end of Test	Average Current per sq. foot	Corrosive Efficiency of Current	Pounds Corroded per Year per sq. foot at Average Current	Pounds Corroded per sq. ft. per Year—for Rates at End of Test
1	Water	.096	.030	.230	1.66%	.076 lb.	.0237 lb.
2	“	.020	.002	.048	3.89%	.037 lb.	.0037 lb.
3	“	.025	.007	.060	1.05%	.013 lb.	.0036 lb.
4	“	.033	.010	.079	4.36%	.068 lb.	.0200 lb.
5	“	.031	.012	.074	5.38%	.079 lb.	.030 lb.
6	“	.106	.055	.254	2.06%	.105 lb.	.054 lb.
7	“	.037	.025	.089	6.88%	.122 lb.	.082 lb.
8	“	.030	.010	.072	4.61%	.066 lb.	.022 lb.
9	“	.066	.030.	.158	2.84%	.090 lb.	.041 lb.
10	“	.096	.010	.230	1.23%	.057 lb.	.006 lb.
11	3% NaCl	.231	.190	.554	55. %	6.09 lb.	5.0 lb.
12	“	.192	.151	.461	80. %	7.42 lb.	5.85 lb.
13	“	.163	.141	.391	40. %	3.13 lb.	2.70 lb.
14	“	.191	.181	.458	66. %	6.07 lb.	5.75 lb.
15	“	.160	.135	.384	69. %	5.35 lb.	4.50 lb.
16	“	.113	.100	.271	62. %	3.38 lb.	3.00 lb.
17	“	.174	.125	.417	69. %	5.77 lb.	4.15 lb.
18	Water	.019	.011	.046	0. %	...	...
19	“	.019	.018	.046	0. %	...	...
20	“	.020	.015	.048	3. %	.029 lb.	.022 lb.

DISCUSSION.

J. G. Wray, M. W. S. E., (Chairman): We have all been much interested and instructed by Professor Burgess' paper. The results presented indicate that while electrolysis of iron imbedded in concrete does take place, the concrete itself appears not to be disintegrated by the electrolytic action nor destroyed by the corrosion of the metal. I read a paper not long since (I do not remember the name of the author) in which it was stated that electrolysis destroyed the concrete immediately surrounding the metal. This would obviously greatly reduce the strength of the reinforced concrete. Professor Burgess has already shown that electrolysis does not have this effect.

I realize my inability to discuss this paper intelligently but know that there are others here who can do so, much better than I can. Before calling for a general discussion, however, I would like to make a few suggestions, which I believe have a bearing on the subject and may perhaps explain the apparent discrepancy between the results obtained by Professor Burgess and those of other investigators. I would suggest the possibility that the porosity of the concrete or the composition of aggregate, whether of limestone, granite, gravel, etc., may have something to do with the amount of electrolytic action which takes place. It is also possible that the richness of the mixture or the age of the concrete may affect the results of the experiment.

William B. Jackson, M. W. S. E.: We are indebted to Professor Burgess for this valuable and interesting contribution to our knowledge of electrolysis of iron when imbedded in concrete. What I have to say is hardly in the line of discussion but more in the line of query.

The tests described in the paper show, other things being equal, a greater electrolytic action upon iron imbedded in concrete which is immersed in salt water than when immersed in fresh water. This suggests the thought, whether putting salt in the water used in making concrete—which is so frequently done when laying concrete in cold weather—may not have the effect of producing concrete wherein imbedded iron is abnormally affected by electrolysis. I shall be glad to have the author's opinion as to this.

The table covering the results of the tests of electrolysis upon iron in concrete immersed in lake water showed a decidedly less percentage of corrosion in the cases of concrete made with one brand of cement from that made with the other brands. This naturally raises the query as to whether there is some particular ingredient either lacking or present in this one cement which produces concrete which tends to protect the iron from electrolysis better than concrete made with the other cements.

J. N. Pierce: I am in the electric line, and as I was listening to the paper it occurred to me that there are various other things that caused this corrosion and that it was a matter of keeping the moisture out of the cement; then it occurred to me that some of the waterproofings are an iron compound mixed with the cement,—and I would ask if that would not be really very detrimental to use? I have heard a great many salesmen in connection with reinforced concrete talking about mixing this moisture-proof substance with the concrete before putting it around the iron. It seems to me that this would be more harmful than beneficial, on account of increasing the conductivity of the cement.

Professor Burgess: Do I understand that those moisture-proof materials have iron in them?

Mr. Pierce: Yes. Ironite is one of the cheap materials. I think the general idea is that these moisture-proof materials work into the pores of the concrete and expand with corrosion.

W. H. Finley, M. W. S. E.: Wouldn't it be a good idea to put current through all reinforced concrete and thereby increase the adhesion?

Wm. Seafert, AFF. W. S. E.: About 10 % more bond is obtained with rusty material than where there is no scale.

Carl A. Keller: It sometimes becomes necessary to use cinder concrete in proportions of one of cement to seven of cinders. I have seen cases where this cinder concrete had to be placed in thicknesses of 18 in., and there has been some question as to the desirability of putting the cinder concrete next to the iron beams or iron posts that may be imbedded, and in order to avoid any corrosion a cement coating had been applied to the beam before laying the cinder concrete. I wish to inquire of Professor Burgess if he can explain to us the action of the cinder concrete and the iron. I would also ask if some tests could not be made similar to those explained to us this evening, using cinder concrete around the pipe and in various electrolytes that were mentioned in the paper?

A. O. Anderson, M. W. S. E.: I was wondering how these tests were made, and whether it would not be advisable to make a similar set of specimens, put them under similar conditions, and not send any current through them. I rather think the specimens that were left in that salt solution for 108 days would show some rust without the cement, and we need not charge up all of that rust to the electric current.

Mr. Fowler: I would ask Professor Burgess about the corrosion near the surface. The electrolyte, as I understand it, was below the level of the top of the concrete. Did you take any precaution, with oil, for instance, covering the electrolyte or the concrete so that there would be no access of air? Where was the most corrosion? Then, in removing these specimens from the concrete, what precaution was taken to prevent actual scaling of the iron,—by a hammer blow, for instance?

G. T. Seely, M. W. S. E.: It seems to me that this paper is a very timely one, and one that is of considerable value for local application. It has been proposed here in Chicago that the subway be constructed of reinforced concrete. In this subway there would be railway lines carrying either single units or trains which would require heavy electrical currents. These currents, if there is much reinforcement, would tend to be carried in the structure itself, it seems to me, which would not only present the danger of electrolysis where the current would leave the reinforced structure, but also perhaps in the length of the structure. I do not think the danger is as apparent as it may seem, for the reason that the difference in the voltage between the ends of the reinforcement, if the reinforcement were not continuous, would be very small, and, as Professor Burgess pointed out, if the difference were less than the polarization voltage it would probably have no effect. It seems to me that this might be something which would be well to determine by experiment. If there is such an effect, it would have an important bearing upon determining the degree of insulation of the track rails in the subway.

Oscar E. Strehlow, M. W. S. E.: I do not know that I can say anything definite on this subject, because methods have to be tried to determine the effect. But in retaining-walls a condition sometimes exists in which the prices of the reinforcing material and cement, and the crushed stone and sand, and of back filling behind the retaining-walls, are such that a reinforced concrete wall and a gravity masonry wall are about equal. In view of this uncertain and untried question of electrolysis, it seems to me it would be a safer proposition to stick to the gravity wall.

Mr. Finley: I think that one of the valuable lessons we can learn from the experiments of Professor Burgess and those who have preceded him is that it is necessary to use great care in the construction of our concrete, particularly in the reinforced concrete; that is, to get a mixture as nearly impervious as possible, and also to see that it is thoroughly waterproof.

In 1904 I prepared an article on the necessity for waterproofing engineering structures in concrete, and called attention then to the possibility of the destruction of the reinforcing material in concrete by electrolysis. At that time I knew of no experiments having been made to determine that fact, nor could I find that the matter had really been given any attention. I am glad to see that since that time there have been experiments made in that line, and that while the question is not determined positively one way or the other, the results shown by Professor Burgess' experiments and others do indicate very clearly that we should exercise great care in building reinforced concrete.

R. H. Rice, M. W. S. E.: There are a couple of questions that I would like to ask. I understand from the paper that the results show nothing as regards the actual conductivity of the concrete itself, and the current that passes through I presume is conducted entirely by the moisture in the pores of the concrete. I would like to ask when the observations were made, whether the concrete had been immersed for a length of time sufficient to allow it to become entirely saturated with the water?

The other question was in regard to the time of the polarization. I presume that as soon as the concrete was placed in the water and became moist the polarization E. M. F. rose to its maximum value almost immediately, so that if a potential difference of 8 volts was applied, and there was a polarization E. M. F. of say 1½ volts, the actual potential difference which was causing this current flow would be then 6½ volts, and that would be the potential difference to which the concrete was subjected continuously throughout the experiment.

F. F. Fowle: This paper, it seems to me, is one of very great interest to us all. Of course it is one which is rather difficult to discuss because of the meagreness of the subject, but its present importance can hardly be overstated.

One of the interesting features in regard to electrolysis, not only in this case but in others, is the question of polarization, and I would like to ask the author what his experience has been in regard to the characteristic current flow when the voltage is diminished. It is very clear that after there had been a flow of current sufficient to establish a polarization of, say, 1½ volts, a reduction of the impressed E. M. F. would result in a diminished flow of current. It would be interesting to know whether he started out with any E. M. F. values of about 2 volts or less, and what characteristic flow was observed under those conditions. In a great many cases of electrolysis the potential difference does not exceed perhaps 2 volts, except for a very short period of the day, possibly during the peak of the load. In that case it would be very instructive to know how the current characteristic is affected. This has been a matter of some controversy in various cases of ordinary electrolysis of underground pipes, where some have contended, on the one hand, that any applied E. M. F., however small, would result in damage; while it has been contended, on the other hand, that the polarization would quickly shut off any current flow of dangerous magnitude.

Another point occurs to me, in regard to which there appears to be an entire lack of data up to this time. This concerns the question of whether or not the concrete is affected in any way by the flow of current through it or by any electrolytic corrosion that may be taking place. In Prof. Burgess' suggestions of new fields for investigation it seems that we might add several things, one of which would be tests for tensile, and compressive strength, of samples in which the current had been allowed to pass between two electrodes at opposite ends of the test piece. Such tests would embrace variation in the current density and the duration of flow; and comparisons would be made with similar test pieces not exposed to possible corrosion or disintegration.

In reinforced structures we depend, of course, on the steel for tension, and the stresses are communicated from the concrete to the steel by the resistance to shear along the junction of the two materials. This seems to be still another profitable field for investigation, which is perhaps more important than the one first suggested. Obviously many chemical changes are taking place along the plane of shear, at the junction, and any weakening of the structure at this point might be attended by disastrous results in practice.

D. A. Abrams, JUN. W. S. E.: I did not wish to speak of electrolysis, but I heard a question some time ago regarding the effect of the rust on the bond strength between the concrete and steel. I know it is well recognized that rusted steel will give a higher bond strength, but I do not believe it will necessarily follow that the rust generated after the concrete was placed around the steel would give the same result.

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W. O. Hotchkiss, M. W. S. E.: It occurs to me that many of our reinforced concrete structures are not in a similar situation with the test pieces. Those with which we ordinarily deal are alternately wet and dry, or very considerably in the degree of moisture. It occurs to me, in this connection, that possibly with the sediment drying off from the entrance of air, the concrete might become filled with the oxidized iron within the concrete, and in that way become far less porous, so that the electrolytic destruction of the iron would be greatly retarded. I should like to ask the author his opinion in regard to that,—what would be the effect of the alternate dryness and wetness of the structure?

CLOSURE.

The Author: Referring to the chairman's inquiry as to the possibility of the porosity of the concrete or the composition of the aggregate having something to do with the amount of electrolytic action which takes place, there is no doubt that there is a marked influence produced by the physical character of the concrete such as porosity and perhaps its chemical condition. The free lime, for example, ought to have a retarding influence. It would appear that if a concrete could be made non-porous, it would then offer a protection against electrolytic action.

Mr. Keller brought up the question as to the use of cinder concrete. As I understand it, the objection to cinder in concrete is that the particle of carbon coming in contact with the iron forms a local couple; there is no doubt that the possibility of electrolytic action exists where such a couple is formed. This would be entirely prevented by the use of a thin layer of uncontaminated cement, as mentioned by Mr. Keller. I doubt, however, even if the cinder does come in contact with the iron, that the couple would be active on account of the polarization which is set up. The maximum voltage of that couple would be not much more than one volt. The polarization would probably be equal to that, and the current would be stopped unless the air or oxygen could get at that cinder and depolarize it, which probably would not be the case. It is my opinion that there will not be much damage to the reinforcement due to local action by the imbedded cinders.

Our chairman presented the query as to whether the formation of iron rust in the concrete did not block up the holes and therefore stop the flow of current. That would be the case if the rust formed within the concrete or at the surface of the iron, but our experiments showed that it does not so form unless air gets in, and this action of the air must be very slow, while the concrete is all wet. Rust forms on the outside surface of the concrete, the iron existing in the concrete in the form of a soluble salt as a ferrous or ferric chloride. It is only when that is oxidized that the rust forms. The presence of salt in the concrete would undoubtedly make that concrete more conductive.

Our experiments would show that salt, in addition, makes the corrosive action of the current much more marked, and it appears, therefore, that the use of salt in mixing concrete might constitute a disadvantageous factor.

The presence of iron compounds in the concrete, put there to render it waterproof, ought not to have any disadvantageous effect unless such compounds be soluble electrolytic conductors. The chemical composition of the materials referred to is not given, and opinion as to their influence cannot well be formed. As pointed out before, the matter of making concrete moisture-proof seems to be a highly important one from the standpoint of electrolytic corrosion.

Referring to Mr. Jackson's inquiry, it does not appear that our tests have been sufficiently accurate, nor the results sufficiently conclusive, to warrant the deduction that there is a material difference in the electrolysis resisting property of concrete as influenced by the particular brand of cement employed. It is probably true that there may be such difference, and especially would this be true if the deficiencies in cement make decided differences in the density and permeability of the concrete. It should be a matter of further investigation to determine if there are any constituents in cement and concrete which have a notable influence on electrolysis.

The question has been asked, whether the kind of iron itself may have a marked influence on the electrolytic corrosion. While the tests referred to were limited to but one kind of iron,—a mild steel,—I am of the opinion that the kind of iron makes very little difference, as far as the current efficiency in the corrosion is concerned.

Again, it has been asked whether there might not have been a similar amount of corrosion if the pipes had been exposed to the salt water without the flow of current. While I have not referred to the existence of check samples in this work, such samples were prepared and it was found that the salt water produced very little natural oxidation during the period of the test where current was not flowing.

In answer to another question: The corrosion takes place in the most marked degree at the surface of the concrete block. This level was several inches above the surface of the solution in the tank, but it was really at the level of the solution since the solution worked its way up into the concrete block to the surface of it by capillarity, so that the corrosion really takes place at the surface of the electrolyte.

The tubes were removed and brushed; there was no scale on them, and they were just as a piece of iron would look after taking it out of an acid solution. They were simply washed off and brushed, and the rust which is apparent on these samples —the brown rust—is the result of subsequent exposure to the air. If the air could get at the concrete around the iron reinforcement occasionally, as one of the speakers suggested, it would result in the formation of this brown rust throughout the concrete and ought to act as a retarder. It ought to fill up the pores with a non-conducting material,—the brown rust is practically non-conductive,—and make the resistance high.

The question of polarization is a really important one in the study of electrolytic corrosion, and it is one which has been given too little attention. We have under way at the present time another series of tests in which the applied pressures are 0.5 of a volt from the beginning of the test, and it is found that the polarization is somewhat less than 0.5 of a volt. There is a slight amount of current flowing, and whether that amount of current is going to produce 90% electrolytic corrosion, or 80%, or only 1 or 2%, is something that we have not as yet found out. We have found no reference in literature to other work which has been done on this polarization subject, and it is worthy of attention.

The average pressure throughout the day may be in some localities 8 volts, setting up a polarization pressure of 2 volts. When this applied pressure drops down below 2 volts, there ought not to be any electrolytic action until that polarization is diminished by the action of the oxygen of the air.

The current is carried through the cement electrolytically by the electrolyte in the voids in the concrete. The United States Government chemists have conducted a rather exhaustive investigation of the conductivity of soils,—sand and clay and other materials,—and the results are of a good deal of interest to any one studying the practical electro-corrosion phenomena. They find that the conductivity is purely a question of the electrolyte between the particles of sand or clay.

The suggested importance of studying the electrolytic corrosion, in view of the possibility of a subway in Chicago, is very interesting, but from what I have recently read in the papers that is a purely theoretical speculation.

THE ENGINEER AND WAR.

Caryl Davis Haskins.

Presented March 22, 1911.

In no other nation are the highly educated professional classes at once so ignorant of, and out of sympathy with, all that pertain to militarism, and at the same time so arrogant as to national military prowess, as in this great country of ours.

After devoting some twenty-three consecutive years to utilitarian engineering, and in the meantime having made a diligent study of the relation between engineering and military stability, I welcomed eagerly the opportunity which was held out to me last autumn, to present the conclusions and suggestions which follow in Chicago,—the nation's most daringly progressive city.

I am assuming that there are very few men of the scientific professions who give any heartfelt credence to what might be termed, *Peace by contract and promise.*

In all history the interrelations of men, whether national or commercial, have been unrestrained by treaties, either of tradition or contract, in the face of conditions of violent provocation or stress, and however great the ethical convictions of the race or nation in times of cool judgment, they have, essentially without exception, failed to withstand the pressure of most of those conditions which lead to war.

It is by no means my purpose to discuss that gravest of topics, universal peace, peace by disarmament, peace by mutual agreement, or peace by coercion; in the latter theory there is perhaps some ultimate hope, but only under *conditions which involve the co-operation of a high percentage of the professional engineering classes.*

It would seem that modern commercial and trade conditions render periodic, though perhaps less frequent, war more certain than in the past ages, because more dependent upon national vested interests, which must inevitably clash from time to time, and less dependent upon hot-blooded impulse, which those same vested interests of nations serve largely to hold in check.

It is my theory, and one which can probably be substantiated by logic and example, that the real termination of warfare will come when war is rendered, by invention and skillful preparation, so deadly, so quick, and so effective an undertaking as to check itself by reason of its very efficiency and precision.

This is a condition which the engineering professions must largely bring about, and doubtless will bring about sooner or later, and it is with the duty of the engineering professions, and incidentally of the other learned professions, in regard to national militarism with which I wish to deal.

The science and practice of war was, of course, originally a mere struggle of brute strength, between individuals or groups of men armed with clubs and stones. As the intelligence of man increased, the skill invested in thoughtful preparation began to prevail over mere force and numbers, less at first on the battle field itself in the skill of well administered fighting, than in the skill of the engineers who devised and prepared defensive armor, the catapult, the cross bow, the early firearms, and finally the great defensive and offensive works of Vauban.

It is rather noteworthy, and fairly well established by the statistics of history, that the relative periods of actual peace in relation to the periods of warfare have increased in almost direct ratio as warfare has become potentially more destructive; so too we find, with a few exceptions, that as the means for the destruction of many and of much by the relatively few became more certain and effective, the percentage destroyed in actual warfare became smaller.

This is chiefly the work of the engineer, and a very large proportion of the best engineering work of the first sixteen centuries of the Christian era found its direct incentive in war.

Not until war began to be a highly specialized art do we find the engineering talent of the nation or the people at large abandoning the consideration of these matters and relying upon those specially trained for that paricular work.

There is scarcely a phase of modern effective warfare which is not almost wholly dependent upon effective engineering in one of its specialized forms. The good modern army is simply a highly trained, highly organized, and also a highly complicated, machine, dependent in its every detail upon proper engineering; for I consider sanitation and surgery as akin to the engineering professions.

The great nations of Europe, confronted as they are by a more persistent daily reminder of the possibilities of war, although perhaps by no more real menace than ourselves, began to meet this situation a century and a half ago by the establishment of large standing armies, but today even those nations which maintain the largest standing armies recognize and admit their dependence upon the systematic co-operation in times of peace and war of the engineering forces of the nation, which are not regularly a part of the military machine.

I venture to assert that we stand alone among the great nations in our neglect of this situation. Why we thus stand apart, at the peril of our future, is hard to understand, but I think that we can find three explanations:

1st. Our system of education and our national atmosphere are both conducive to the creation of a certain national self-satisfaction and arrogance, which has given rise to, and which I suppose must continue to give rise to, much fine oratory and a strong belief, upon the part of the ignorant, in the doctrine of the "strength of the right arm of justice," and other kindred doctrines, which have little to support them except eloquence and a sense of romance.

2nd. A state of national growth and prosperity which, for an hundred years, with one brief intermission, has called for the devotion of all of our engineering and intellectual talents to the development of unusual resources, backed by unused wealth, and—

3rd. The natural and thoughtless pride which comes from great numerical strength and great national wealth.

Of this last condition at least, and of the other two to a considerable extent, we find the *reductio ad absurdum* in the case of China, a country of numerical strength beyond parallel, through which, however, a little handful of scientifically-equipped and controlled soldiers was able to march, essentially unmolested in the face of universal hostility, to the relief of a few dozen of their fellows, who had been shut up in the midst of a great hostile populace for a long period. Of course our condition is not that of China, and presumably can never be, but the analogy is not so completely lacking as it might seem to be.

It is not my purpose to tax you further with generalities; I however thought it necessary to state these few premises to provide a base for the arguments and suggestions which follow.

Essentially every educated and intelligent man devotes a considerable percentage of his whole working time to the providing of insurance for himself, his interests, and his loved ones; broadly, he provides little or no time to the provision of insurance for the nation. This is not true of other nations.

I am fortunate in having a somewhat wide acquaintance among the engineering profession in Europe, and I find that a high percentage of European engineers whose daily avocation relates to what might be termed gainful pursuits are, nevertheless, definitely contributory to national insurance,—that is, national defense,—through direct or indirect connection with their own national military establishment.

For example, one of England's most prominent engineers, at the head of an extensive and prosperous commercial engineering establishment, is also a Colonel of Reserve Electrical Engineers, and a constant advisor of his government's military establishment, in those specialized arts relating to applied war, along the lines of his chosen profession. He is a sure and valuable reliance of his country's military establishment, and takes part in his own special organization, while he is in reality no burden upon it.

I have in mind the chief engineer of a prominent engineering establishment in France, an engineer so engrossed in his daily commercialized vocation as to find an absolute minimum of leisure for relaxation; nevertheless this man is an officer in the Engineer Reserve of his country's military force, and takes part in contributing advice to the military establishment of the nation in regard to his specialties in time of peace, and would be an effective and especially trained instrument in the emergency.

I have in mind, also, the chief engineer of one of Japan's greatest mining corporations, who is, without interference with his daily engineering work, an officer of high rank in Japan's Army Reserve, ready to command specialized troops, whose function it is to conduct the mining and tunneling operations incident to advanced scientific warfare on a large scale. The emergency found this man pursuing his own profession, along military lines, on the face of 303 Metre Hill, in front of Port Arthur.

These examples might be multiplied beyond the patience of any listener, but not out of the professional material within our own territory.

Let us contrast our own national condition with that which these cases typify. I know but one really prominent engineer in America who devotes any appreciable portion of his time, thought, or effort to the practice or theory of national defense along the lines of his chosen profession. I want to make this distinction. There are many very able professional men who find recreation—and useful national insurance, if you like—in our national guards of the various states, but almost none of them along engineering lines. I shall say more of this a little later. Even he is not following the work along the important lines of those things he knows best, but is coming as near to it as he can with the opportunities our system affords.

Of course we can all cite a dozen or more men within the scope of our personal engineering acquaintances, who are doing or have done things useful to the government incident to national defense, but the incentive has almost always been commercial. They have conceived, or invented, or developed, or promoted some system, structure, or device which, while often highly useful and a great addition to defensive science, was in reality launched by them and pushed forward by them gainfully. I do not condemn that. I simply say that it is another issue altogether.

I do not doubt that a good many who have listened to me thus far feel that my statements have been unpatriotic and disrespectful to our people as a nation. Nothing could be further from my thoughts. I believe that we have been in a certain channel of development, and that this channel is wrong and should be changed. I believe that no nation has a higher or more enduring sense of patriotism or a more self-sacrificing spirit of national devotion in the emergency, but we all know what this alone means in the test.

The more scientifically anything is conducted, the longer it takes to provide the material for the undertaking, and the longer it takes to train the people involved to use that material. So we find in a little conflict like that which we experienced with Spain, where our opponent was in reality a negligible quantity, the mortality was sickening in relation to the work done, and the waste of material was out of all proportion to the effective effort expended; while the aftermath of our Civil War, waged in its early stages by great bodies of men who were little more than semi-organized mobs, today makes the cost of our military establishment comparable with the great establishments of the great nations of Europe, because of the cost of the pensions.

Of course we have an army; its actual strength today may be set down roughly at about 80,000 men. I have been told by competent European military authorities that it is probably the best army, *for its size,* in the world. By the best army is meant the most efficient force, both as to personnel, equipment, and government. This army of ours, reinforced by all our Militia and National Guard, comprising, in short, most of the able-bodied men in the United States trained to any knowledge—of even the most simple applied military arts—constitutes a force numerically somewhat weaker than that which Servia, with an area of 18,600 square miles, and a population of 2,500,000, could put in the field.

It is not my purpose, however, to advocate militarism in its ordinary sense, and especially it is not my purpose to advocate a very large standing army, for I believe that such a standing army is not practicable under our form of government.

The average professional engineer in America is, I venture to believe, not only ignorant of our own army, but also of the scientific side of all military matters. I do not believe that the average American engineer realizes that the whole work, equipment, and use of an army is a matter of good or bad engineering. I do not believe that we engineers of America are giving either the moral or the scientific support to our military interests or our military establishment which they should receive from us.

A high percentage of our best engineers, I find, regard the army officer as a man of more or less definite leisure, whose principal duty consists in putting his men through certain more or less formal and useless physical movements, and whose culture and education relates more to the pleasant amenities of social life than to any serious and definite work.

How many American engineers realize that the training of at least a high percentage of our army officers is almost wholly an engineering training, and ought to be a specialized training, if there were enough men to go around?

The course at West Point devotes a high proportion of the four years to mathematics and science, and our army sustains three struggling and ill-supported schools, devoted almost exclusively to strictly engineering work. These are post-graduate schools, always in lack of facilities and funds, always struggling to get some little thing from Congress, often without avail, and always without even the recognition, let alone the solid support, of the great and powerful body of American engineers who are so uniformally in ignorance of what they are doing.

These three schools are, the Engineer School, at Washington, D. C., the Artillery School, at Fortress Monroe, Va., and the Army Signal School, at Fort Leavenworth, Kan. We might perhaps mention a fourth school—Field Engineer School at Fort Leavenworth.

At these schools we find army officers who are typical engineers, striving under the most adverse conditions to acquire, with the help of equipment inferior to that which would be tolerated by many third-rate scientific schools, and under the guidance and instruction of other officers of the army who have become specialists in their particular lines of work, a specialized engineering education, without the help or knowledge of their brethren in civil life.

No great manufacturing organization would contend for one moment that fire, however remotely probable, was not a contingency to be reckoned with, and this whole paper is premised upon the fact that however reluctant we may be to admit it, warfare is a national contingency, we hope very remote, but none the less to be reckoned with and provided for.

A prominent legislator recently, in arguing this question which I am discussing, thought we would never lack for a multitude of men in the emergency. No true American who has studied his people can doubt this for a moment. Who, however, would attempt to operate a great factory, or dig a great irrigation ditch, without especially trained foremen? If it were attempted, as it would have to be were no such men available, then the *foremen would have to be developed on the job,* and every civil and mechanical engineer knows what that means in time, in money, and in life.

We made an efficient army in the Civil War—we spent at least the first two years making it, and even today history shrinks from recording what it cost.

It is, then, I contend, since so much of the work to be done is essentially engineering work, the very solemn duty of the great engineering brotherhoods of civil life to interest themselves in, and give support to, sane, safe, and farseeing military engineering preparations.

The most immediate and obvious way to help this situation is to give time, care, and thought to the study of our needs and problems, to the vast mass of unread literature which sets forth our needs annually, and to intelligently support all of those military engineering projects which bear such study and analysis with all of our organized force and intelligence.

I do not know that this has ever been done in our country in times of peace, and it would seem to be one of the easiest of things to do.

Many a highly trained and intelligent engineer has contended that preparedness for war involves real engineering measures and projects only on the basis of a most liberal interpretation of the word engineering. This is an error. For example, let us take the prescribed specialized electrical engineering knowledge which is required of engineer officers in our own army at the present time. I quote from an authoritative source. Their duties relate to—"The installation of electric power plants and electric power cables, at all fixed positions"; "In sea-coast defenses, the use of applied electricity under fixed and emergency conditions, for motors, for the operation of ammunition hoists," which must be well ordered and maintained to give a reliable and uninterrupted source of ammunition. "Electric systems of range finding, fire control and direction control"; "Current for seach-lights and search-light operation"; "Current for the illumination of emplacements and range-finding stations"; "Current for the operation and handling of guns and gun carriages." These applications carry with them all of the implied studies in relation to power-house construction, character of current, location, and administration, and, of course, go into prime movers of all classes; the special mechanisms for, and the operation, preparation, and construction of the electric submarine mine system, with all of its adjuncts, special methods, and problems incident to fire control and the electric firing of great guns, and all that goes with the upkeep of such a system.

In field operations we find that a study of the electric illumination of distant areas, to disclose and to embarass the movements of the enemy, are prescribed, and familiarity with all of the equipment necessary thereto is required. This goes into specialized branches of the art incident to the effective lighting of bridges, the use of field lights to hinder or prevent mining and sapping, the forming of light zones to impede the operation of hostile search-lights, the construction of all kinds of electrified defenses and entanglements, such as, for example, were used so extensively in the Russo-Japanese war.

We find the study, construction, and operation of electrified military railroads prescribed.

In mobile field operation we find field electrical apparatus of many kinds prescribed for study and operation.

In short, the military electrical engineer, and a high percentage of all officers, must be familiar, not only with the use of electricity for the daily applications in connection with which we best recognize it incident to communication, power, and light, but also a vast number of specialized applications of those various branches which we do not have to meet.

This is all true again of mechanical engineering incident to the machinery for the operating and serving of heavy guns, building and operating railroads, and maintenance of mechanical equipment; while, of course, the civil engineer is the military engineer, without his spurs.

We must remember that even with our ample resources we have found it expedient as a nation to turn to the army finally to find trained engineers to dig the Panama Canal, and we must remember that from our little army we have drawn essentially all of the responsible chiefs who are today directing that work in its various phases.

Incident to this suggestion of co-operation, study, and support, might it not be feasible for our organized national engineering bodies to give some systematic consideration to this particular phase of the situation? Might we not in each society have a standing committee of our very best material, whose function it should be to place itself at the disposal of the scientific branches of our army, to study, report upon, and make recommendations in regard to the needs, the problems, and the difficulties of that special branch of engineering in connection with which each particular society is most deeply concerned?

I can well conceive an organized movement which would result in much good with little effort. Might we not, for example, have a report from an appropriate committee of the Western Society of Engineers, endorsed perhaps by a committee of the American Institute of Electrical Engineers, and the American Society of Mechanical Engineers, to the effect that "House Bill Number X should receive the unanimous and unwavering support of the entire engineering profession, for this reason—and this—and this—and this?"

May we not imagine that this system might go further and provide reports or recommendations addressed either to the proper military authorities on the one hand, or to the parent society on the other, suggesting in the first case that certain methods or measures be tried, and, on the other hand, suggesting that legislation be initiated with a view to providing, etc?

Such a system would at least insure the provision by Congress of the very few thousands of dollars needed to provide adequate housing, equipment, and material for the proper and efficient training of officers in specialized lines, and those few of us who know about it would no longer have to blush at the knowledge that we, as a nation, house our post-graduate Engineer School, where engineer officers get a final one-year course in electrical and mechanical engineering, in an old and dilapidated dwelling, so ill-equipped as to laboratories as to suffer in comparison with the high school of many a small town.

But this is but a simple part of our neglected duty towards the military establishment.

Accept it, please, as an axiom, that we could be engaged in no first class war without providing a *first* field army of at least 500,000 men, which would require immediately, at the very lowest figure, not less than 2,000 (I state my figure conservatively) officers with specialized engineering training, as well as 12,000 to 15,000 men specially trained in engineering work.

Where are we going to get them?

The common answer is that a vast number of skilled engineers with all kinds of specialties are instantly available, and will make good officers, and that an inexhaustible number of skilled artisans are available to make specialized troops.

This is perfectly true; it is merely a question of time and selecting the right ones, but ours has been a history of national failure in selecting the right men for officers, especially technical officers, in the first stages of war. We have not the machinery for doing it, and we select the wrong men in a high percentage of cases inevitably; of course time eliminates them ultimately, but if one deducts the whole period necessary for winnowing out and training, one has a formidable array of conditions big with danger.

At the present moment we have in the army of the United States some 180 engineer officers, more or less, and something under 50 officers of the Signal Corps. This is our total regular equipment of officers whose training has been specialized for the many engineering necessities of their service. It is conceded that there are too few of these men to properly carry on the work of the present establishment. Of course a large percentage of the officers of the artillery are highly trained in engineering branches, but there are too few of them and they belong to an exceedingly specialized branch of their profession, and not one of them could be spared for any but artillery work.

The little force of engineer officers and signal officers would be instantly broken to pieces by the formation of a volunteer army, because, being highly skilled, they, in common with a great number of regular officers from the line branches, would be withdrawn to take command, in high ranking positions, of volunteer troops.

Now of course an army is a headless and a footless thing, without specialized engineering organizations under specially trained engineer leaders in the following branches: Railway troops; transport and subsistence troops (involving, of course, automobile and lowry transport in large measure); bridge builders; road builders; fortification builders and sappers (civil engineers pure and simple); signal troops (electrical engineers of the telephone and telegraph variety); submarine mining troops (electrical engineers of a highly specialized variety, not paralleled in civil life); and electrical engineers (pure and simple as we know them) for the operation of light and power machinery. Of these latter, for example, England, with her small and somewhat unique force, has one full *reserve* regiment; Germany and France more, while we in our regular establishment can spare few, if any, people for any of these specialties, and such work as has been done in our Militia and National Guard along these lines is, with a few shining exceptions, almost worse than nothing at all.

What can we do abut this?

There are three things which might be done.

I have said that for the first field army of 500,000 men we would need a minimum of 2,000, and in practice probably nearer 2.500, highly educated officers, trained to engineering in its various branches both by education and practice. Back of and under these men we would need from 15,000 to 20,000 specialized troops of the mechanical and engineering type.

There is no need to point out that in a considerable measure such troops, and in a much larger measure such officers, cannot be made in a brief time.

The first and most obvious remedy would be to provide from 40% to 70% of the requisite number in the regular standing army. Certain European nations have tried this. The plan has its merits, but for American conditions we may dismiss it, because it would provide an increase in one branch of our army ridiculously disproportionate to the army as a whole; for that and other reasons it would be impossible, and perhaps undesirable, to secure this through legislation. Incidentally, too, so great a force of engineer officers, if part of the regular establishment, would be very highly trained soldiers as well as engineers, and would therefore be instantly dissipated to command volunteer line troops in case of war.

This plan is at once the most simple and the most impracticable for our conditions.

The second alternative is to develop these technical officers in connection with the National Guards of our various states, which are now in reality, as the result of recent legislation, the first reserve of our regular army.

The objection here lies in certain human qualities of the men who are at present our Militia material. The difficulties are real though subtle.

As a rule, very young men are attracted to the militia. A wholesome quality of primitive manhood leads them to prefer the essentially military side of the work, and the result is that, since our militia system is highly democratic in its fundamentals, the recruiting and enlistment and maintenance of our Militia goes forward along the lines of least resistance, and this is not in the direction of specialized development.

Furthermore, I find that serious-minded engineers are rarely attracted by the National Guard. Almost always we engineers think of it as "play soldiering."

I am convinced, therefore, that we cannot hope for any considerable measure of development in specialized engineering troops, and especially officers, in the National Guard.

Nominally there are a few such organizations. I have seen something of them myself, and regular officers who have inspected them have assured me that they have found them to be the very best of amateur soldiers, exceptionally well equipped mentally and physically as infantry, with a fine elan, but in no sense can they be regarded as technically specialized soldiers.

For the time being, therefore, and for a long time to come, I believe that we may dismiss any hope of material relief of the situation which I am trying to depict, through the National Guard.

Finally we come to what I predict must be the ultimate remedy for the situation, under our national conditions of life: The creation of a corps of inactive technical reserve officers, followed, after this is well established, by localized bodies, forming the nucleus or leaven of the technical end of the volunteer army.

Let us see what this would mean. It would mean that some 2,000 professional engineers—electrical, mechanical, civil, mining, and sanitary—would be required to become reserve officers of the United States Army, just as, for example, the higher grades of mercantile marine officers, like the officers of the Cunard and White Star lines are reserve officers of the British Navy.

It would mean that these civil life engineers would be required to pass examinations paralleling those, and perhaps exceeding in difficulty, those laid down for technical officers of the regular army, in connection with the technical non-military branches of army work.

Of course with such examinations would be coupled physical requirements and probably some little prescribed training in the more formal portions of the soldiers' profession.

The average civil-life engineer with this proposition put before him as here stated, would, nine times out of ten, say, "I have neither time nor inclination, nor will my own interests permit me, to enter into any such plan."

The "inclination" is the thing to which I am chiefly addressing this talk; the questions of "time" and "interest" can be disposed of by logic; inclination can be met only with a plea.

Were such a force in operation today, I have no hesitation in saying that it would be found that the endorsement resulting from the successful achievement of a commission which would imply high proficiency, because of the system of careful selection, would constitute its own tangible reward in civil life.

It would be found that the municipality requiring a chief engineer for the construction of a bridge would give preference, all things being equal, to the men who had been endorsed by an established and impartial system of investigation, as against his brother who had received no such endorsement.

Self-interest, then, would favor the sacrifice, if such it can be considered.

As to time, no material sacrifice of time would be required under such a system. The object would be to provide with certainty, proper well-selected technically-skilled material for officers—men proven capable of conducting their technical duties skillfully along the lines of their own profession.

The plan would not contemplate, as I conceive it, the final completion of a soldier engineer; the purely routine and functional duties would at no time be required to be developed in so high a measure as in National Guard line officers, for the development along these lines in case of war could be acquired quite rapidly—certainly as rapidly as by non-technical volunteer officers.

Certain lines of reading might, and probably would be, prescribed, as would also, probably, periodic examination. Perhaps very brief periods of practice service might be necessary, but these would amount to little or nothing, except in times of national emergency when, we may fairly assume, on the basis of the country's past history, a high percentage of all men, technical and non-technical, would be ready to do their part.

The provision of a force of reserve technical intelligence along these lines might be compared, from the nation's standpoint, with the provision of an adequate reserve of rifles, of field guns, or of ammunition, and the absence of such a reserve of technically talented men may be compared with the condition necessitating the utilization of any guns, any cannon, and any ammunition which might be hastily picked up for the emergency.

Our forefathers went into the Revolutionary War armed with fowling pieces, and all sorts of weapons, but I have never heard it contended that this condition was desirable.

Prominent engineers with whom I have discussed this idealistic scheme have contended that our military establishment would by no means tolerate the creation of such an institution as that which I am suggesting. Twenty, or even ten, years ago I believe that this would have been true; today I do not believe that it is; the needs are too well realized, and our technical military authorities are eagerly receptive towards any plan destined to provide the nation quickly with efficient rather than inefficient tools.

What use would an establishment of 2,000 technical reserve officers be without the troops to go with them? This is the commonest question of all. The answer is that it is always easier to find men to put up a bridge than it is to find men to design it and to supervise its erection. Furthermore, a much larger proportion of this total number of officers would be required for work other than that immediately connected with the work of troops than the layman realizes.

It is only necessary for an engineer in commercial life to depict to himself the number of skilled technical men, having no relation to the actual physical workers, who would be required to properly administer the daily work of a commercial undertaking employing 500,000 people, to bring the truth of this statement to the most unmilitary thinker.

With our present force of engineer officers of the Engineer Corps of the Army, many less than one-half are serving with troops, and probably less than 25% would be serving with troops ninety days after the creation of a field army of 500,000 men. I believe, then, that if no reserve of technical troops were created, the principal benefit sought would be achieved, but it is doubtful if the work, once initiated, would stop with the provision of a reserve of officers.

European nations have found it advisable to go further, providing a force of national reserve troops, not in due proportion to the number of officers, but enough men fitted for the non-commissioned grades, drawn from the wide field available of foremen, skilled artisans, and mechanics, to constitute a nucleus or skeleton around which could be rapidly assembled, in the emergency, enough properly selected volunteers to complete the complement.

I do not doubt that many of you gentlemen feel the suggestions which I have made to be a fantastic dream. It lies with the engineers of America whether they shall prove a dream or a reality. I do not claim to have presented a new thought; European nations have followed similar plans for a long time. Notably this is true of Switzerland and Holland, and, in a somewhat different way, of Germany and France.

The leading minds in our own military establishment have done much thinking along similar lines, as is indicated by the fact that one of the highly technical branches of the army has already addressed manufacturing establishments throughout the United States, having in their employ technical men proficient along the right general lines, asking that the names of individuals be suggested to the appropriate bureau of the War Department as men who would probably be qualified to give efficient service in purely technical engineering lines as volunteer officers in an emergency army.

Already our army has, well established, a system of medical reserve officers, organized not exactly along the lines here suggested, and perhaps along lines less attractive to the advanced and successful technical man, but purposed to achieve much the same results.

I have heard it said that every self-respecting American believes that he has within himself the qualities necessary to make a General, and that the only reason that this same typical American does not feel well qualified to become an Admiral is the fear that he may become seasick.

There is much truth in this, and it is also true, based on our past history, that when volunteers are required, they are not only forthcoming in vast numbers, but they are all insistent in their determination to get into those branches of the service where they seem likely to see the greatest amount of fighting in the shortest possible time.

This is especially true of the men who seek to become officers,—it would be regrettable were it otherwise—but it means that in the formation of a great emergency volunteer army, the technical branches are not favored by the men with the military spirit, while the men best qualified for the technical branches, being sober-minded and unexcitable individuals as a class, are, under present national conditions of sentiment, prone to think twice, or even thrice, before tendering their services.

One natural consequence of these conditions is that the vacancies which have to be filled in such numbers, in such haste, are likely to be filled initially by the first cousin of someone's sister's aunt, who is in serious need of a good job.

This whole plea of mine—for my whole talk this evening is nothing but a plea—has but one purpose, a very definite one, to direct the sober, earnest, and particularly the sustained interest and attention, of the largest number of civil-life engineers whom I can reach to an investigation and study of our whole military system—its needs, strength, and weaknesses. It is my hope that as an outcome of such sober consideration, a great national good may follow, as must always be the case when popular interest at the hands of the large number of intelligent people is enlisted in any cause.

I make no plea for the adoption of the specific plans which I have suggested; I have presented them merely for lack of better ones; and would be the first to welcome with acclaim the substitution of others.

But let us do something.

Discussion.

G. T. Seely, M. W. S. E. (Chairman): Mr. Haskins has favored us with an interesting and valuable paper on a most important subject. When the committee was arranging for this meeting they did not anticipate the army maneuvers that are now taking place along the Mexican border, and the paper comes at a time when great interest in military affairs has been aroused.

I am going to call on a gentleman who I think is eminently fitted to discuss the proposition. He is an engineer and at present is leading a strenuous fight at Springfield for an appropriation, so he undoubtedly knows something about war.

W. L. Abbott, M. W. S. E.: Mr. Haskins, in going very thoroughly into some of the necessities and necessary provisions for war, omitted—very probably intentionally—the point which our chairman touched upon,—the sinews of war. I do not propose to suggest that the Western Society of Engineers furnish the sinews in any sense of the word.

Mr. Haskins' paper is a very carefully prepared discussion of a condition which sober-minded people recognize exists in this country, due largely to our confidence in our neighbors after one-hundred years of peace which has prevailed upon the northern border, and to the satisfactory condition, as far as we are concerned, which prevails upon the southern. We have on the Pacific coast now a bare suggestion on the one shore of what the European nations feel to be all about them, and it is that feeling—that distrust of their neighbors—which keeps their military spirit alive and keeps them in a state of military preparedness. The little unrest which we feel towards our neighbor in the east or the far west I think is doing much at this time to make the people of the United States consider how they would be situated in the event of hostilities, which, if they come at all, will come out of a clear sky. Usually when this country goes to war, it goes without much immediate preparation. The preparation, to be effective, must be worked out years in advance as in the historical case of the invasion of France by the German army; the German commander-in-chief had only to turn to his desk, take out the program of the campaign, and set his armies in motion. Unfortunately, so far as we all know and believe, we have no such condition of preparedness in this country, and when trouble comes, if it should come, the want which will be felt will not be that of men. We can recollect how it was in the case of the Spanish War. Companies and regiments were raised and drilled, and thronged the doors of the recruiting office waiting for a chance to be mustered in. Our own Naval Reserve here in Chicago got into the Navy finally by dint of political influence and by disbanding its own organization and enlisting individually. The want will not be of men. It will be for trained men, and such men can be obtained only by long training.

I imagine that war now, and more so in the future, will be a war of engineers. It will be an operation which will require the skill of those who can quickly transport men and material; who can quickly build roads and bridges; who can quickly construct defenses and entanglements, and this with any material which happens to be at hand. Not only that, but it will require men who are familiar in general with the science of warfare, which is a science and no longer a trade. The officers of the Government training, army and navy, will of course have command of all this. They are, of course, being dissipated into civil life and are not immediately available. Many of the graduates of technical schools, however, have some rudimentary military training, and that, supplemented by their engineering training, should make them available for military service in many branches, if they could have the advantage of occasional training in some of these graduate schools—schools for officers, of which Mr. Haskins has spoken.

I think the suggestions which he has made, if followed up and given the encouragement which their importance warrants, would, in the course of a few years in this country, as has been proven in other countries, provide, for the defense of the nation in times of emergency, a body of men from whom could be drawn immediately that technical ability which is indispensable now to warfare and which is absolutely necessary to cope with similarly trained men of a possible enemy.

It is unusual to discuss war subjects so far inland as this and in the piping times of peace, but it is in just such places and in just such times that these things should be considered, and if through the efforts of Mr. Haskins or some one else there should be a movement put on foot to furnish the right training for such officers, I have no doubt that the Western Society of Engineers and its members would gladly realize and do their duty in such a movement.

W. F. M. Goss, M. W. S. E.: I interpret the paper of the evening as a call to engineers for wider sympathies and for action along broader lines, and as such I am sure that we all agree with the author in the view which has been expressed.

Engineers are busy people; they work with a high degree of concentration, and it is sometimes difficult to rouse them from their peculiar tasks. It is for this reason that we need calls to public service of every sort, and we do ourselves credit and our profession honor when we accept such calls as they come. By so doing we show that we are not engineers merely, but also citizens and lovers of the public welfare.

That the Western Society of Engineers is not unmindful of its responsibilities in these directions is made evident by its recent action in sending a committee of its distinguished members to inquire into the needs of the University of Illinois. It is no small matter that busy men were willing to take the time necessary for such a trip, to make a study of the conditions they found there, and to formulate a report for presentation to the Society. But such action is well designed to show the character of the men, and to prove that their interests are broader than the routine of their day. It helps to demonstrate that engineers as a class feel their responsibility to society, and that they are really doing things in addition to their daily tasks which are significant and fine.

Fay Woodmansee: One point brought out in Mr. Haskins' paper which has interested me very much is the lack of equipment at our present schools. I think this is a matter which should be taken up by the engineers of the country, to see that the schools for training of technical men of the Army are provided with equipment which shall compare favorably, not with our high schools but with the best universities in this country. I think that is one point which should be brought to the attention of the people in general, so they will understand that our military men who are being trained as expert men for fighting must have proper equipment in order to get results. I believe it would be a splendid thing if the engineering profession of the country would take up the situation offered in Mr. Haskins' paper and see that Congress makes the necessary appropriations for equipment of the military schools for the men to work with.

I agree heartily with what the speaker has had to say regarding the need of good men of engineering ability to look after certain lines, and I believe, as Mr. Haskins has said, that when war comes upon us, unless we are properly equipped in this particular way it will take some time before we get the organization together. That has been borne out by our wars in the past, and I sincerely hope that something can be done to awaken engineers to the realization of this fact.

Morgan Brooks, M. W. S. E.: Like the last speaker, I am surprised to hear of the lack of equipment in the Government graduate schools of engineering, but I am also surprised to hear that there are four graduate schools in engineering of the United States Army. I only knew of one before—the Engineers' School at Washington.

I think I am not mistaken in believing that the Naval Academy has been sending students to the Massachusetts Institute of Technology, at Boston, for post-graduate work or for advanced work in engineering, particularly the engineering corps. It occurs to me that the Government might be encouraged to send either its own army graduates from West Point, or other engineers who might be recommended by the different societies or colleges, for post-graduate courses in military engineering; that is, in engineering that is particularly adapted to military needs in the various engineering schools that are already well equipped, in this country and perhaps abroad. We have seen in this country a great many Chinese and Japanese students in agriculture and engineering, and the engineering education in some cases I believe is directly in line with the work that those young men are expected to do in case of emergency at home. The Chinese are particularly active in that way at the present time, not only in the United States but also in Germany, and why should not we send out students to colleges in foreign countries for such work? Would it not be proper for our own universities to offer their facilities, as perhaps a recognition or proper return for the great benefits that the Government has given the technical schools in this country, in the land grant colleges, as they are called? We might perhaps co-operate with the Government by offering facilities for advanced engineering work of that sort.

F. J. Postel: I am much interested in this paper, because I had a little experience in the Engineer Corps of the Army during the Spanish War. While doubtless all of those who volunteered at that time were trying to do the best they could, it was a good deal like "the blind leading the blind." It is all over now, and so I am willing to admit that I was in charge of some work I knew very little about, and the men that were under me and from whom I tried to get some information knew less than I did about it. I have every reason to believe that my superior officers were equally in the dark. There seemed to be very little organization. Our officers—some of them at least—were good engineers from the standpoint of civil life engineering, but of the work that they had to do they knew little more than the non-commissioned officers. Being a Sergeant brought me into rather close touch with the officers in immediate charge of the work on which I was detailed. From my conversation with them and their discussions with each other in my presence, I was soon convinced that the problems they had to meet were entirely new to them also, and all this confusion was due largely to lack of training which they might have obtained in the form of some reserve Corps of Engineers, such as the speaker of the evening suggested.

There is another feature of picking up men at random and organizing them into volunteer engineers that does not work out just right, and one little incident in connection with our own organization will serve to illustrate that very well. Some of the officers in our regiment were not very well versed in engineering matters and less so in military matters, while some of the privates were really very good engineers. One day when we were at Montauk Point—it was after Shafter's army came back—quite a large detachment of our regiment was working on roadmaking around the hospital. There was a shortage of topographical map draftsmen at Shafter's headquarters, and simply because this detachment was nearest (geographically) to headquarters, and it was known to be an engineering division, an officer was sent over to the detachment to inquire whether there was any man present who had ever worked on maps. One of our privates said that he had, and they took him over and tried him. As a result he was put in charge of some important work in the map-making division and served there on "detailed duty" for several weeks at just that kind of work. Here was a man that was working on the road doing a laborer's work and I think none of the officers or non-commissioned officers knew that he had ever had any experience with map-work and was well fitted for that kind of work. The officers knew little about the special training and ability of their men, and if the right man was selected for the right work, it was only by accident.

It seems to me that some organization in which the abilities of men along those lines could be discovered and developed would certainly do a great deal of good. The Engineer Corps of the Militia or National Guard has the drawback that it does not appeal to a good many of the engineers because most of the work of the National Guard is really police duty. Men who would not hestitate a minute to enlist in a time of war do hesitate a long time about doing police duty every time there is a little riot somewhere.

Mr. Seely: There was a movement on foot here last summer to organize an engineering department or Engineer Corps connected with the Illinois National Guard. I would like to ask if any one in the audience knows anything about that movement —whether anything was done or not.

Col. Lewis D. Greene, (of Illinois National Guard): I came here as a guest to listen, not to make speeches. I have none to make. However, I can answer the question which has just been asked.

Under the law of the state of Illinois we are entitled to the organization of a company only of engineers. There was a company in the state some five or six years ago which was mustered out; it fell to pieces from lack of interest or something of that sort, and has never been reorganized. For a year and a half past, especially during the past year, efforts have been made to find engineers of a military training that would go in and take hold and build that corps up; and if any of you gentlemen have been put through the military paces, and will come up to Division Headquarters, Illinois National Guard, we will give you a job. I already have my eye on Mr. Postel, who has owned up to some military service.

I think that the speaker of the evening has very greatly broadened the view of the engineering profession as applied to the military art. Many of the staff corps have to use the principles of engineering. We have what is called the Quartermaster's Department, the name of which in no way describes what the duties are. All transportation, and frequently the actual building of roads and bridges, to say nothing of warehouses and all kinds of buildings which come in their regular work, is handled by the Quartermaster's Department, and it would be a help if we could have the support of you gentlemen, even in a tacit way. I say we, because I have been in the Army all my life, and am now on duty here with the Illinois National Guard, acting as an executive officer of the Division Commander, General Young, whom many of you probably know by name, if not in person.

There is a great necessity for men who are outside of the Army to study military affairs and know something of what some day will surely happen to us, just as in days past it *has* happened to us. We have always been caught without preparation when dragged into wars, as has been called to your attention by Mr. Haskins. Because we had no trained soldiers, the war of the Revolution was a heartbreaking tragedy, and the war of 1812 was a ghastly joke,—from a military viewpoint. The enormous expense in paying for deaths and disabilities, in money merely, and the awful expense in life caused by our Civil War, due to absolute lack of preparation would have supported a picked navy and army from the war of the Revolution until now, and would have put down the war of the Rebellion in the first three months of its existence. What is the use of an army where there is no war? is the popular question. Our people do not see the use of military preparation; they prefer the other way; and I suppose we shall have to accept the situation and take our killing when it comes along.

With an organized body here locally, and in general all over the United States, as engineers, if you work in your organizations and publications with sympathy for military education and cry down the arguments that are constantly being presented to put the people to sleep with an idea that wars have ceased, and at least let them be mentally prepared for something of that kind, that will help to a great extent. It may give Congress the desired impulse to give the general staff of the Army a legal right to make plans for the future, which it has not now. It will not cost one cent to put a bill through Congress to make those plans, and lay out an organization which will become legal on the outbreak of war. The idea is to get the official sanction, that is all. Yet Congress has not done that; not because of lack of interest but because it is an abstract question; there is always something else to attend to which is of immediate importance. They are much more interested in political and industrial matters than in any future defense. Of course, in one way that is not quite fair; they do not take much interest in technical military matters because they do not understand them from the soldiers' view-point. Congress has been exceptionally liberal in making provision for the Army and for the National Guard during the past few years, but we want it to be more liberal, because the increases asked for will give much greater relative national insurance in an effective army.

The National Guard has until very lately been called "Militia," and that name was not changed until the men began to change their ideals and habits. The word "Militia" calls to mind the stories we used to read of the annual muster, where men who had been enrolled in any given county got together once a year, grotesquely armed and appareled, many of them carrying cornstalks for arms; they were counted, filled themselves up with corn whiskey, and went home. That was the annual "Gineral Trainin'," and is what the Militia consisted of; their value as soldiers was somewhat less than zero, because some people had the idea that they were soldiers. The present mental attitude and physical work of the men who belong to the National Guard is very different. There is an immense amount of work being put upon them. Twenty-five percent of the National Guard officers in this state either resigned or retired last year,—they could not stand the pressure, as there was too much time and work demanded of them. A bill was introduced in Congress in this last session in behalf of the National Guard of the United States. It was approved by the committees of both Houses, and was passed by the House of Representatives. It then stood at the door of the Senate with two-thirds of the members inside in its favor, but in the rush and turmoil of the closing days of the session it could not get to a hearing and therefore was not passed. The bill advocated the payment of a pittance to the men and officers of the National Guard to compensate them for the actual cash outlay they pay for the *privilege* of standing ready to drop business and profession and answer a call for armed service. The greatest relative pay of officers was to go to the company commanders, who really have to do more work than anybody else. Relatively as to the pay of the army, the enlisted men would get the greatest amount, twenty-five percent of the pay being given to non-commissioned officers and privates in their respective grades in the United States Army; this provides $3.75 per month for a private. That bill had practically the friendship of Congress, but was not passed. I do not know what the new Congress will think about it.

Now, you gentlemen are in the habit of moving great bodies and raising great weights, and if you will get your mental leverage for this work under the minds of the people and the present Congress to make the National Guard a real military reserve at the relatively trifling expense that it will cost, I think the people of the country will thank you for the assistance you have given, some day when war breaks out

The National Guard has gone forward a vast amount since the Spanish War; it is a very different proposition now from what it was then, but there is still ample room for improvement.

Mr. Seely: If any one needs an object lesson to awaken his interest in any movement of this kind, I advise him to read two books that I read recently. Perhaps some of you have already read them. I refer to Prescott's "Conquest of Peru," and "Conquest of Mexico." With the proper organization and proper leadership, there is no reason why 200 men under Pizarro should have conquered a nation of hundreds of thousands, if not millions, even if they did have improved firearms and appliances for warfare. The same thing happened in China a few years ago, as pointed out by Mr. Haskins.

R. F. Schuchardt, M. W. S. E.: I would like to ask Mr. Haskins whether any organization has taken steps toward any definite action in regard to this very excellent movement.

Mr. Haskins: No, not yet, because these thoughts and suggestions which I have presented tonight have never been presented before to any organized body. I wanted particularly to present the matter in Chicago first. That it will have the support of a good many individuals,—individuals who should have wide-reaching influence,—I know from their own assurance

In particular, I do not wish to stampede anything. I want to get this Society and other societies to thinking on the subject. I do not pretend for a moment that I have offered a final solution of the problem. I have only tried, in a crude sort of way, to present a statement of what the problem is.

One other thing (in common with every engineer, I think), I am supremely sensitive lest I should be thought an alarmist. I should dislike to think that anything I have said tonight could be taken as an indication that I believe we are going to have a war, or that war is any more imminent now than it has been for years. All that I have pointed out is in the way of machinery and appliances for preventing war, not conducting it, because it is my belief that the best invitation to disaster is to remain content with a bridge so weak that it will not fulfill its needs.

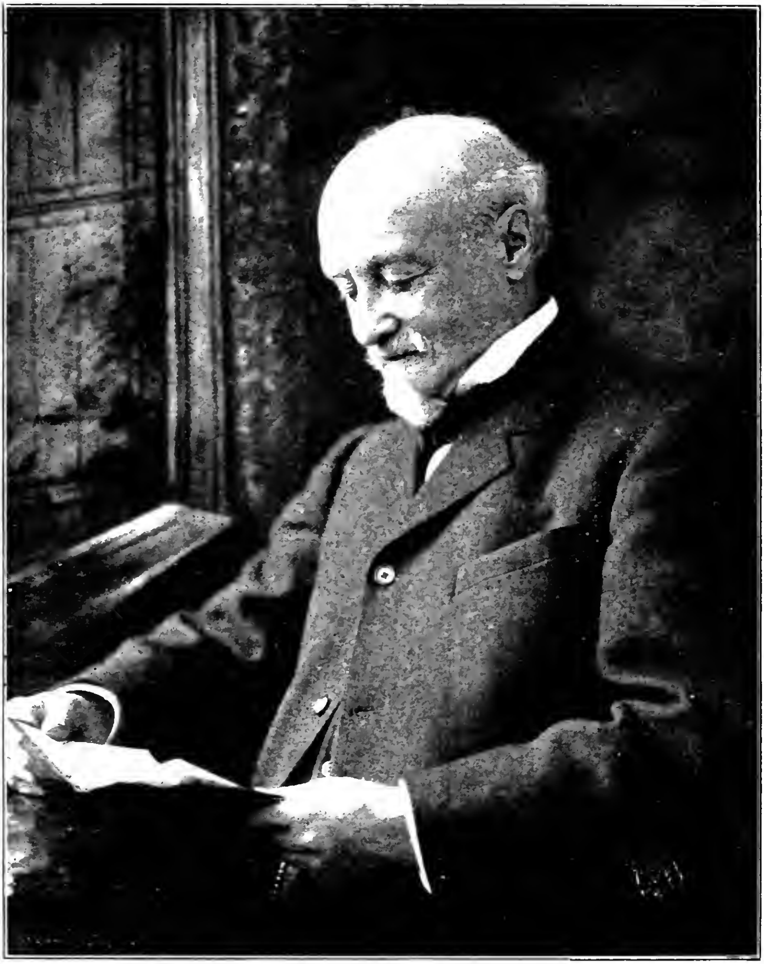
L. R. Pomeroy: I wish to speak about the tendency of the Government being more in sympathy with the general engineering of the country, and that tendency has been in the way of getting together. About three years ago a committee of the American Society of Mechanical Engineers met a committee of officers from Sandy Hook proving grounds, and they invited the Society as a body to visit the Government reservation, furnishing a special train to take the members down to the Sandy Hook proving grounds to look things over. That was a great revelation to us, because ordinarily it is very difficult for a layman ever to set foot on the reservation, and we asked why there was this change of attitude. One of the officers said, "We have been thinking a good while over this situation; a number of our engineering officers are members of your Society, and we wanted to have the Society become interested in the engineering problems that we have to face. We have permission from the Government to invite you here and show you practically anything we have." We went there and spent the day. The officers manipulated the disappearing-gun carriages; fired several of them at targets; exploded mines; fired mortars located in the deep pits, and various officers gave lectures on the plans and processes in vogue involving engineering features. This is directly in line with Mr. Haskins' statement that things are opening up towards the point of having the engineers of the country coöperate with the Government to the mutual advantage of both.

George M. Mayer, M. W. S. E.: I happened to read in the Chicago Tribune a few days ago that a German officer of the army had expressed the opinion that we will have war with Japan eventually, and this statement is confirmed by Americans returning from the Philippines, whether army officers or not. So Mr. Haskins has only expressed the opinion of the country at large that we should prepare for war.

CLOSURE.

The Author: Some one tonight suggested the possible desirability of training certain technical officers of the Army at some of our leading technical colleges, as has been done by the construction corps of the Navy to some extent. In an unsystematic way—unsystematic because unprovided for—this has been done in a very small measure by certain of the technical staff corps of the Army. The great difficulty lies in the fact that there is a shortage of men in almost all of these corps. They are all—or substantially all—seeking increase to get enough officers to take care of the immediate work in hand at the present time. There is no systematic provision of funds for the outside education of officers, though there have been sporadic provisions. There are not officers enough to spare, to send any away, for such work. I am by no means sure that it is the best way for the training of such men. It might be the best way for a very few.

In the case of the construction corps of the Navy, we have a specialized line of designing work, which is probably taught better in civil-life schools than in any navy school. To the best of my knowledge and recollection, it is very nearly the only actual designing work that either service has to do. I make a great distinction between what I term designing engineering and coördinating,—the difference between the man who designs a piece of machinery and the man who is a consulting engineer; who lays down the methods and applications of use of groups of machinery for any purpose. The Ordnance Corps of the Army does require a certain number of designers. Other Army engineers, whether they are of the Engineer Corps, the Signal Corps, the engineering branches incident to artillery work, or the Quartermaster's Department, are substantially all of the class which we in civil life call coördinates,—bringers together in the proper way of various things; selectors, pickers out, and arrangers. So high a percentage of the advance technical courses in our mechanical engineering, civil engineering, and electrical engineering schools devote a large part of the educational period to an analysis of design that when we bear in mind that these men must get the very greatest amount of the actual mental material which they need in the very shortest time, we will find that these men would have to go to our technical civil-life schools under the handicap of having to absorb say forty or sixty per cent of information which would not be immediately applicable. I think this phase of education must be provided for in some other way.



Octave Chanute, C. E.

IN MEMORIAM

OCTAVE CHANUTE,

Died November 23, 1910.

This memoir records the professional career of an Engineer closely identified for the last sixty years with the development of transportation on land and in the air.

Octave Chanute was born in Paris, France, February 18th, 1832. His father was Professor of History in the Royal College of France, in Paris, and in the year 1838 accepted the appointment of Vice-President of Jefferson College in the State of Louisiana; he was a resident of Louisiana until 1844, when he removed to New York City and engaged in literary pursuits. His son, Octave, who was six years old when the family came to this country, completed his education in New York, and became, to use his own expression, thoroughly Americanized.

Mr. Chanute began work at the age of seventeen in 1849, on the Hudson River Railroad. This beginning was made, as was usual at that day, at the very foot of the ladder. Young Chanute introduced himself to the Resident Engineer at Sing-Sing and asked for employment. When told that there was no vacancy, he asked for permission to serve without pay as a volunteer chainman. This was somewhat reluctantly granted, with the result that within two months the young man was put on the pay-roll at $1.12½ per day, and thought his fortune made. Nor was he far wrong, for Mr. Chanute has often said that this was the only position he ever applied for and that he had been continuously engaged since that time without having to solicit employment.

He remained with the Hudson River Railroad for four years, until the completion of construction, when he became Division Engineer at Albany, in charge of terminal facilities and of maintenance of way.

In 1853 immigrants were pouring into Illinois to buy government lands at $1.25 an acre which are now selling at more than $50.00 an acre, and railroad construction was proceeding rapidly. Mr Chanute came west with Mr. H. A. Gardner, his former Chief Engineer on the Hudson River Railroad, and was engaged on the surveys and construction of what is now a portion of the Chicago & Alton Railroad, between Joliet and Bloomington. Before this was quite completed he became Chief Engineer of the eastern portion of what is now the Toledo, Peoria & Western Railroad, and built that Road from Peoria to the Indiana State Line, a distance of 112 miles. Upon its completion

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NOTE: The committee appointed by the Western Society of Engineers to prepare this memoir is almost identical with the committee appointed by the American Society of Civil Engineers, and the similarity that may be observed in the memoir as published by both societies is thus explained.

May, 1911.

in 1857 he remained in charge of maintenance of way until 1861, when, the Road having gone into the hands of a Receiver, he accepted the position of Division Engineer of Maintenance of Way of the Pittsburgh, Fort Wayne & Chicago Railroad between Chicago and Fort Wayne. This appointment was given him by his old friend and Chief, Mr. Gardner, who one year later recommended him for the position of Chief Engineer of the reconstruction and maintenance of the Western Division of the Ohio and Mississippi Railroad, from St. Louis to Vincennes. This he accepted, but six months later the Road changed hands, by one of those sudden vicissitudes not uncommon in those days, and Mr. Chanute, having by that time attained a reputation for industry, efficiency, and fidelity, received simultaneously several offers of employment. He accepted that of the Railroad which he had first served in the west and became the Chief Engineer of the Chicago & Alton Railroad in 1863, and as such took charge of the reconstruction which, by that time, had been found necessary, for these early American railroads were cheaply built. His duties included the maintenance of way and the building of an extension of the line from Alton to St. Louis.

During this connection, which lasted until 1867, Mr. Chanute submitted a competitive design for the Union Stock Yards of Chicago, and this having been selected in preference to a score of other designs, he was made Chief Engineer of the Yards, and supervised their construction in addition to his railroad duties.

These various engagements brought him in contact with prominent railroad men, and he was next offered the design and construction of the pioneer bridge over the Missouri River at Kansas City. This offer was accepted, and he tendered his resignation as Chief Engineer of the Chicago & Alton Railroad. The Board of Directors of that Railroad, accepting his resignation, passed a resolution of regret at the severence of his connection with that company. The construction of the Kansas City bridge, across a stream so rapid, shifting, and ill-reputed as the Missouri River, involved what were, at that time, a number of novel engineering problems. It was successfully completed in July, 1869, and attracted general interest as the first bridge built over the Missouri River. A book, giving an account of the construction of the Kansas City bridge, was written by Mr. Chanute and Mr. George S. Morison, his principal assistant Engineer, and published in 1870.

While engaged in completing the Kansas City bridge, Mr. Chanute was placed in charge of the building of several railroad lines, extending into Kansas, planned to secure a portion of the cattle trade coming overland from Texas: first that of the Kansas City, Ft. Scott & Memphis Railroad, from Kansas City to the line of the Indian Territory, then of a parallel line, now known as the Southern Kansas division of the Atchison, Topeka & Santa Fe Railroad, then of a connecting line between these two, and lastly of a line from Atchison northward, the whole comprising the construction of about 400 miles of railroad, and incidentally thereto the design and construction of the Union Stock Yards of Kansas City. These various works were completed in 1871, and Mr. Chanute then became the General Superintendent of the Southern Kansas Railroad.

In 1873, when the Erie Railroad was reorganized, Mr. Chanute was made Chief Engineer of that Railroad. It was then proposed to double-track this road, to standardize its 6-foot gauge, to extend the line to New England and to Chicago, and generally expend about $50,000,000 in improvements. This promised well for the Engineer, but the financial panic of 1873 upset the arrangements made in England for funds. Less than $5,000,000 was expended on the Road, which served, however, to double-track the main line, change the gauge to standard and to improve the gradients so that during the ten years which Mr. Chanute spent on the Erie the average freight train could be increased from 18 cars to 35 cars. For a time he was in charge of the motive power of the Railroad so as to readjust the distribution of locomotives.

Upon his return to New York in 1873 he observed that "Rapid Transit" in that city had been under discussion for nearly twenty years without any definite results. The necessity for more rapid communication was evident; many projects for superceding horse cars had been proposed but none was recognized as solving the problem and the public seemed to be completely at sea. After some unsatisfactory inquiries as to the reasons for this condition of affairs, Mr. Chanute concluded that the question would be best settled by investigation through a committee of the American Society of Civil Engineers, and having been made Chairman of such a committee, consisting of W. N. Forney, Ashbel Welch, Chas. K. Graham, and Francis Collingwood, they undertook to collect all the data and facts. These were chiefly contained in pamphlets aggregating about 4,000 pages octavo, and after this literature had been digested communications were invited by circular. Five public meetings were held to give hearings to all who chose to appear, interviews were had with organized bodies and with citizens who were likely to possess information, and a canvass was made of property owners and tenants upon the proposed routes.

The resulting report was made public in 1875. It recommended substantially the plan subsequently carried out, i e., the building of four lines of Elevated Railroads along the Avenues, to be operated by steam locomotives, and stated that such lines would be profitable, which was not generally believed by moneyed men at that time. The report was, at first, vigorously assailed by men interested in other projects, but the public accepted it and it was almost immediately followed by the requisite legislation and the building of the Roads.

May, 1911.

In this investigation, the laboring oars were wielded by Mr. Chanute and Mr. Forney, then Editor of the Railroad Gazette, and they wrote the reports and appendices. The former, indeed, had done all of his work at night, so as not to interfere with his Railroad duties, and he found himself so prostrated upon its completion that he had to take a vacation, and he went to Europe for four months to recruit.

In 1880, Mr. Chanute was appointed Chairman of a committee of the American Society of Civil Engineers to report upon wood preservation. The investigation occupied five years, and resulted in the publication of a report of great value, which was the authority on the subject for many years. In 1885, a number of American Railroads called on the Chairman to build plants for wood preservation, and he after that became interested in wood preservation as a business.

In 1883, he resigned from the Erie Railroad and removed to Kansas City, opening an office as Consulting Engineer. In this capacity he had charge of the design and construction of the iron bridges of the Chicago, Burlington & Northern Railroad, between Chicago and St. Paul, and later he performed similar work for the Atchison, Topeka & Santa Fe Railroad on the extension of its line from Kansas City to Chicago, involving, besides a number of minor streams, the bridging of the Missouri River at Sibley and of the Mississippi River at Fort Madison.

As long ago as 1874, Mr. Chanute had become interested in Aviation, but it was not until 1889, when he moved to Chicago and thenceforth made that city his home, that he could find the time to devote himself seriously to the solution of this "Problem of the Ages." With characteristic industry and thoroughness he engaged in an extensive correspondence with men all over the world interested in this subject and gathered and systematized all information of importance which he could find, investigating the records of experiments of the past two or three hundred years. The fruit of these labors appeared in a series of articles entitled "Progress in Flying Machines," first published in the American Engineer and Railroad Journal, New York (October 1, 1891, and following issues), and republished in book form in 1894. This publication was of the greatest importance to the advancement of the art, for not only were all experiments of any importance described in detail and the principles elucidated, but the opinion of the author on the causes of the failure and the probable direction in which improvement might be expected, were stated.

About this time Otto Lilienthal had been making successful gliding experiments near Berlin, and these induced Mr. Chanute to build a Lilienthal glider and attempt experiments with man-carrying models in continuation of his previous experiments with small models. The site chosen was Dune Park, near the present town of Gary, on the sand dunes of Indiana. His purpose was mainly to attain equilibrium in the air, and he hoped to accomplish this by adjustments that should be largely automatic. Unlike unfortunate Lilienthal, who met his death in August, 1896, while making one of his gliding experiments, Mr. Chanute's many experiments—upwards of 200 flights—were free from any misadventure to life or limb. The Lilienthal glider was an unwieldy monoplane requiring great skill in management. It was soon abandoned and a multiplane glider substituted, and this in turn was replaced by the much simpler and more efficient biplane, the prototype of the present Wright aeroplane. These experiments were described by Mr. Chanute in a paper read October 20th, 1897, before the Western Society of Engineers and published in its Journal.

All these experiments and investigations were made in a genuinely scientific spirit and at his own expense, free to all who were interested, and conducted without any thought of pecuniary or other benefit to himself. He had at an earlier time described his efforts with characteristic modesty as "Giving much of his leisure to the investigation of the chances of success in the possible solution of the problem of Aerial Navigation, not with the expectancy of solving it himself, for he held this would be the work of many men by a gradual process of evolution, but with the hope of advancing the question a little, and making the process easier for those who came after him, by eliminating some of the causes of past failures and laying down the principles which will have to be observed."

On October 20th, 1909, just twelve years after the reading of his first paper on Aviation to the Western Society of Engineers, he read his last paper, entitled "Recent Progress in Aviation," in which he described the bewildering record of successful flights that had been achieved, giving a complete chronology of Aviation from December 17th, 1903, when the Wrights made the first successful man-flight in history, to October, 1909.

After Mr. Chanute's death, the Aero Club of Washington said of him: "Lilienthal, Chanute, Langley, and Maxim are the four names that will ever be inseparably linked with the early stages of flying-machine development, the stages that preceded the successful invention of the first man-carrying machine by the Wright Brothers. These four men elevated an inquiry, which for years had been classed with such absurdities as the finding of perpetual motion and the squaring of the circle, to the dignity of a legitimate engineering pursuit."

Mr. Wilbur Wright in "Aeronautics" paid him the following tribute: "If he had not lived, the entire history of progress in flying would have been other than it has been, for he encouraged not only the Wright Brothers to persevere in their experiments, but it was due to his missionary trip to France in 1903, that the Voisins, Bleriot, Farman, De Lagrange, and Archdeacon were led to undertake a revival of aviation studies in that country, after the failure of the efforts of Ader and the French government in 1897 had left everyone in idle despair. Although his experiments in automatic stability did not yield results which the world has yet been able to utilize, his labors had vast influence in bringing about the era of human flight. His 'double-deck' modification of the old Wenham and Stringfellow machines will influence flying machine design as long as flying machines are made. His writings were so lucid as to provide an intelligent understanding of the nature of the problems of flight to a vast number of persons who would probably never have given the matter study otherwise, and not only by published articles, but by personal correspondence and visitation, he inspired and encouraged to the limits of his ability all who were devoted to the work. His private correspondence with experimenters in all parts of the world was of great volume. No one was too humble to receive a share of his time. In patience and goodness of heart he has rarely been surpassed. Few men were more universally respected and loved."

Mr. Chanute became a member of the American Society of Civil Engineers on February 19th, 1868; served as a Director for four years, Vice-President for two years, was President in 1891, and for the five succeeding years was ex-officio a member of the Board of Directors.

He was elected an Active Member of the Western Society of Engineers July 12th, 1869; was President in 1901, and was elected an Honorary Member January 5th, 1909. Some years ago he presented to that Society a fund of $1,000.00, the interest of which was to provide bronze medals to be awarded annually for the best papers on Civil, Mechanical, and Electrical Engineering subjects. It is noteworthy that the committee to award prizes for papers read to the Society in 1909 reported, after Mr. Chanute's death, that his paper of October 20th, 1909, on "Recent Progress in Aviation," was the first in merit of all the papers submitted during that year and the Society presented the medal to his family.

He was elected an Honorary Member of the British Institution of Civil Engineers May 21st, 1895.

He was an Honorary Member of the Canadian Society of Civil Engineers, a Corresponding Member of the French Society of Civil Engineers and also of the Chilean Society of Engineers.

He was a Member of the American Railway Engineering Association, the American Institute of Mining Engineers, the Society for the Promotion of Engineering Education, and the American Association for the Advancement of Science.

He was a Fellow of the American Aeronautical Society, an Honorary Member of the Aero Club of America, and was President of the Illinois Aero Club. He was also honored by foreign Aero Clubs. The Aeronautical Society of Great Britain awarded him a gold medal in recognition of his distinguished services in promoting the art of aviation.

Mr. Chanute held the degree of Doctor of Engineering from the University of Illinois.

Mr. Chanute was Chairman of the Executive Committee of Engineering Societies which had charge of the International Engineering Congress at the World's Columbian Exhibition in Chicago in 1893.

He was a frequent contributor to the publications of Scientific Societies and to the various technical journals.

A list of the various contributions to Engineering literature, prepared by the deceased, begins with a paper on "Pneumatic Bridge Foundation," published in the Journal of the Franklin Institute in 1868, and ends with a paper on "The Present Status of Aerial Navigation." This last paper was published in "Science," on December 29th, 1910. This list contains 60 titles, the two principal ones being his books on "The Kansas City Bridge" and "Progress in Flying Machines," which have been referred to.

In his relations to his fellow men it is sufficient to record that he was unselfish, just, and kind. The present generation needs no eulogy of him, and for posterity it may be simply stated that he possessed the qualities of mind and heart which endeared him to his friends, caused those with whom he came in contact to respect and admire him, and which, ripened and chastened by the hard school of experience, produced in him one of our foremost Engineers, whose busy life was rich in works and achievement, and kindly and generous acts, commanding our admiration and prompting our love.

Mr. Chanute was traveling with his daughters in Europe in the Summer of 1910, when he was taken ill with pneumonia. For a time his illness was of so serious a nature that a fatal termination was expected, but he recovered sufficiently to return to America, and, after a lingering illness, died at his home in Chicago, November 23rd, 1910. His remains were interred at his old home in Peoria, Illinois.

Mr. Chanute was married in 1857 to Miss Anne Riddell James of Peoria, Illinois, who died in 1902. He is survived by a son and three daughters.

Onward Bates,
Robert W. Hunt,
Charles F. Loweth,
Charles L. Strobel,
Committee.

May, 1911.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS.

Extra Meeting, April 19, 1911.

An extra meeting of the Society (No. 743) was held Wednesday evening, April 19. The meeting, under the auspices of the Hydraulic, Sanitary, and Municipal Section, was called to order by Mr. L. K. Sherman, chairman, at 8:15 p. m., with about 80 members and guests in attendance. There was no business to bring before the Section. Mr. John Ericson, M. W. S. E., was introduced, who read his paper on "Investigations of Flow in Brick-Lined Conduits." The paper was illustrated by stereopticon views. The secretary read some written discussion from Messrs. C. F. Schulz, Chief Engineer, Water Department, Cleveland, Ohio; S. G. Artingstall, M. W. S. E., and Rudolph Hering, M. W. S. E. Discussion was also presented by Messrs. T. C. Phillips, C. B. Burdick, A. Bement, C. C. Saner, H. W. Clausen, C. D. Hill, G. L. Clausen, and L. K. Sherman, with a closure from Mr. Ericson.

The meeting adjourned about 10:45 p. m.

Extra Meeting, April 26, 1911.

An extra meeting of the Society (No. 744)—a joint meeting of the Electrical Section of this Society, and the Chicago Section A. I. E. E.—was held Wednesday evening, April 26. The meeting was called to order at 8:30 p. m., with Mr. G. T. Seely in the chair and about 50 members and guests present. There was no business to be considered, so the chairman introduced Mr. A. C. Smith, of Buffalo, N. Y., who read his paper on "Electricity in Ice Plants," the paper being illustrated by some stereopticon views of plants and machinery.

Discussion followed from Messrs. G. T. Seely, E. W. Lloyd, Wm. B. Jackson, H. Niesz, Fay Woodmansee, W. L. Abbott, Paul P. Bird, P. B. Woodworth, G. H. Lukes, Mr. Steinberg, J. H. Delaney, H. S. Pardee, F. F. Fowle, and the author.

A vote of thanks was tendered Mr. Smith for his interesting and valuable paper.

The meeting adjourned about 10:30 p. m.

Regular Meeting, May 3, 1911.

A regular meeting of the Society (No. 745) was held Wednesday evening, May 3. The meeting was called to order at 8:25 p. m., with President O. P. Chamberlain in the chair, and about 40 members and guests present.

The minutes of the preceding regular meeting having been published in the Journal, they were not read. The Secretary reported from the Board of Direction the following list of applicants for membership:

No. 43. William F. Mann, Kokomo, Ind.
No. 44. Allen L. Fox, Chicago Heights, Ill.
No. 45. Jacob S. Spiker, Vincennes, Ind.
No. 46. Frederick A. Smith, Chicago.
No. 47. Charles I. Jones, La Junta, Colo.
No. 48. Charles J. Heinzelman, Chicago.
No. 49. Lloyd E. Ross, Chicago.
No. 50. Samuel T. Mann, New Albany, Ind.
No. 51. John N. J. Hilbert, Chicago.
No. 52. Ervin J. Bayer, Mount Carmel, Ill.
No. 53. La Verne J. Ruddock, Wheaton, Ill.
No. 54. James Warren Bradford, Chicago.
No. 55. Frank L. Stone, Chicago.

Also that the following had been elected into membership:

No. 12. John C. Gustafson, Chicago, transferred from Junior to . . . . .Associate Member

No. 15. Walter C. Douglas, New York..............Junior Member
No. 16. H. W. Rutherford, Chicago...............Associate Member
No. 17. E. S. Pennebaker, Chicago................Junior Member
No. 18. F. E. Bates, Chicago.......................Junior Member
No. 19. Stanley V. Meigs, Pueblo, Colo... ....Junior Member
No. 22. Frank H. Stowell, Oak Park, Ill............Associate Member
No. 24. R. L. Faithorn, Chicago...................Associate Member
No. 25. James E. Cahill, Chicago..................Associate Member
No. 27. David J. Johnson, Terre Haute, Ind.........Student Member
No. 29. C. S. Rogers, Galesburg, Ill.........................Member
No. 32. Charles A. Budd, Chicago...........................Member
No. 33. W. A. Dorcas, Chicago....................Associate Member
No. 34. Julian B. Freeman, Chicago................Associate Member
No. 35. Meyer Fridstein, Chicago...........................Member
No. 36. Edward H. Bangs, Indianapolis, Ind.................Member
No. 40. Frederic R. Charles, Richmond, Ind..................Member

The Secretary also reported that a telegram of congratulations in the name of the Society had been sent to General Grenville M. Dodge, Council Bluffs, Iowa, on April 11, the General's eightieth birthday, as follows:

"Chicago, April 11, 1911.

General Grenville M. Dodge,
Council Bluffs, Iowa.

The Western Society of Engineers, through its officers, offer hearty congratulations on your eightieth birthday.

J. H. WARDER,
Secretary."

The following letter has been received in acknowledgment from General Dodge:

"April 19, 1911.

J. H. Warder,
Secretary of the Western Society of Engineers,
1735 Monadnock Block, Chicago.

My Dear Sir:—

I received your dispatch extending the congratulations of the Western Society of Engineers on my eightieth birthday. It was very kind of them to remember me, and I appreciate it. I had dispatches from all over the country, some of them from engineers who were with me in an early day, many of whom I have not seen or heard from since; also from my comrades and others in civil life. They seem to have taken this day to renew their friendships.

Won't you please extend to the Society my most grateful thanks for their remembrance and my best wishes for their good health, long life and success to each and all of them.

Thanking you, I am,
Truly and cordially,
GRENVILLE M. DODGE."

There being no further business, the President introduced Mr. W. M. Wilson, M. W. S. E., who read his paper on "Stresses in Guy Wires." After reading the paper, Mr. Wilson, by the use of blackboard sketches, amplified some parts of his paper, thus making it more complete.

Discussion followed from Messrs. Ernest McCullough, F. B. Money, S. T. Smetters, W. S. Marston, J. F. Hayford, John Ensink, with a closure from the author.

The meeting adjourned about 10:00 p. m.

Extra Meeting, May 10, 1911.

An extra meeting of the Society (No. 746)—Bridge and Structural Section—was held Wednesday evening, May 10. The meeting was called to order at 8:30 p. m., with Mr. John Brunner, chairman, presiding, and about 25 members and guests present. There was no business to bring before the Section. Mr. W. S. Marston, M. W. S. E., was introduced, who read his paper on "A Study of Economic Construction of Storage Bins and Trestles for Handling of Raw Material at Cement Plants." The paper was illustrated by stereopticon views.

Discussion followed from the chairman and Messrs. C. R. Dart, S. J. Robison, W. S. Marston, Paul P. Stewart, John Ensink, J. Gibson, A. B. Boyer, W. M. Wilson, M. B. Wishard, S. T. Smetters, J. H. Warder, and a closure from the author.

Adjournment.

J. H. WARDER,
Secretary.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

The Forty-third Annual Convention of this Society will be held this year in Chattanooga, Tenn., June 13-16. The headquarters of the Society, the Secretary's office, etc., will be at the Hotel Patten. A good strong committee of arrangements has been selected for the Board of Direction and local members of the Society.

An attractive program has been arranged, but not so full of engagements and business sessions as to be burdensome. Of course, there will be excursions in various directions from headquarters to objects of interest. There will be an all-day excursion to the dam and lock of the Chattanooga and Tennessee River Power Co., going there by steamboat down the river and returning by rail on the N. C. & St. L. Ry. On the Wednesday evening (June 14) preceding this excursion there will be an address on this work at Hales Bar from Mr. G. F. Rowell (Member), Ass't Engineer in charge of the work. The address will be illustrated by lantern slide views. There is much beautiful scenery in and about Chattanooga, besides many points of historical interest. The town was a very important center of activities during the Civil War, being held by one or the other side in the conflict as of great strategic importance. Lookout Mountain is always an object of interest and admiration, and from Lookout Point a very comprehensive view of the valley and the city is had, showing just below the famed moccasin bend of the Tennessee River. Lookout Mountain, Wallens Ridge, and Missionary Ridge surround and dominate, to a degree, the town. W.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Members of the Western Society of Engineers are invited to attend the annual convention of the American Institute of Electrical Engineers, which will be held in Chicago, June 26 to 30, inclusive, 1911. The convention will be held in the new Hotel Sherman. Excursions will be taken daily to points of interest, among which may be mentioned the following: Ryerson Physical Laboratory of the University of Chicago, where the atomic theory of electricity has been demonstrated by most interesting experiments; the electric furnaces in the steel mills at South Chicago; the enormous electric plant at the Gary, Ind., steel works, driven by gas engines; the great central stations of Chicago, famous for their size and modern design; the hydroelectric development of the Chicago Drainage Canal; "Underground Chicago," with its network of electrically operated freight tunnels; the latest large automatic telephone system; several of the largest manually operated telephone exchanges in the world; street railway and other substations of unusual interest; possibly the largest street railway shops in the world, with electric drive throughout, and many other notable electrical applications.

A broad and interesting program of papers on electrical subjects has been arranged. Arrangements for the convention are in the hands of fourteen Chicago members of the Institute, constituting a committee, of which Louis A. Ferguson, 120 West Adams St., is the chairman.

May, 1911.

BOOK REVIEWS

Kinetic Theory of Engineering Structures, dealing with Stresses, Deformations, and Work for the Use of Students and Practitioners in Civil Engineering. By David A. Molitor. McGraw-Hill Book Co., New York, 1911. Cloth; 7 in. by 9 in.; pp. 366, including index. Many diagrammatic illustrations and tables. Price, $5.00.

Those engineers who have taken the trouble to follow the development of the theoretical treatment of structural engineering, as presented by a number of European, principally German, authors, will greet with pleasure this new book of Mr. Molitor's. He has taken the advanced view assumed by these authors twenty years ago, but as to which we have been in blissful ignorance these many years.

It is rather surprising that all American authors have studiously avoided the mention of the law of virtual work in discussing case of statically indeterminate structures or in giving methods of figuring elastic deformations. Still this law is just as a legitimate means of treating questions in statics as is the law of the summation of components or of moments in a structure at rest being equal to zero. The idea prevails that it is very difficult to understand, but it is not any more difficult than it is to understand the action of a couple of equal weights suspended from the ends of a string that runs over a pulley; this is a system in equilibrium, and if one weight is moved or imagined to move 1 in. up, the other weight will move 1 in. down, and the total work done is zero. An argument similar to this can be raised in reference to a truss or a beam. This law of virtual work cannot be proven any more than the other basic laws of equilibrium, except experimentally. It is axiomatic and will readily be accepted as necessarily true after some pondering on the subject. But its application in conjunction with the law of proportionality between stress and deformation within the elastic limit opens up a view and gives a grasp on these questions, which any amount of explanation or speculation never will give. The law of least work receives casual mention only, being as it is a consequence of law of virtual work and the law of proportionality cited above. Mr. Molitor is to be congratulated for having taken this matter up and presenting it to the American readers in the proper scientific light. At the same time the author is not unmindful of the fact that the use of indeterminate structures should be avoided as much as possible, on account of the practical uncertainty as to the final stresses in the completed structure.

In spite of the author's attempted justification of the use of the word *kinetic* in the title, we think that it is used contrary to most peoples' understanding. Müller-Breslau, in treating exactly the same subjects, employs the term *statik* in the title of his work.

The author goes extensively into the use of influence lines both for simple structures and indeterminate ones.

His chapter on secondary stresses is quite complete, but we might add to the works quoted the mention of a full and valuable discussion on the subject by W. Gehler, 1910.

A whole chapter of 28 pages has been devoted to a treatise on lock gates—a rather special subject for a work of this general character. We realize the author's partiality on this point, as his practice has led him to study the problem thoroughly.

The last chapter on fixed masonry arches treats of this subject on the basis of the laws of elasticity. A good many valuable truths are pointed out, not the least of them being the undesirability of "building fixed arches in this progressive age."

There is one thing for which we wish to commend the author most heartily, and that is his mention of sources of information and the names of investigators and years of their published works.

In reading the ordinary American book on engineering, one gets the impression that here is a collection of facts which has been gathered personally, and theories which have been developed personally, by the author, and nothing in the history of the human race has been attempted before along these lines.

Mr. Molitor has happily given up this attitude of thinly covered self-glorification formerly indulged in by writers in the field, and does not hesitate to state that this acknowledgment of merit where it belongs "has been shamefully neglected by many modern writers." G. N. L.

Engineering Law. Vol. I. The Law of Contract. By Alexander Haring, C.E., LL.B., LL.M. Mem. Am. Soc. C. E.; Professor of Bridge and Railway Engineering, New York University; Mem. Amer. Soc. of Eng. Contractors; Attorney and Counsellor-at-Law. First edition. Cloth; 9 in. by 9 in.; pp. 518. Myron C. Clark Pub. Co., Chicago. Price, $4.00.

This book is evidently the first volume of a series to be devoted to law from the point of view of the engineer and student of engineering; and very properly it is devoted to contracts. The author's object, as he states, has been to provide a textbook to supplement the lecture and recitation courses on the law of contracts given in some of the engineering schools. The book, however, may be read and studied with profit by engineers, as well as by students preparing for engineering work, for there is probably no profession in which a knowledge of legal principles is more necessary than in the engineering profession, considering the complicated situations which the engineer must so frequently handle in which he often stands between conflicting interests and where, in many cases, he is so far from headquarters as to make consultation with legal counsel inconvenient or impossible.

In its general treatment of the subject, the book follows along customary lines. The first chapter treats of the character and inherent elements of the contract; the second, its formation, including mutuality consideration and kindred matters; the third, the parties affected; the fourth, its interpretation; and the last chapter, its discharge.

Each chapter is divided into sections and each section begins with a statement of general principles. Then follow, in each instance, several leading cases illustrating the application of the principles abstractly enunciated, the decisions, in parts of them, being quoted verbatim following the usual case method of law instruction. These leading cases do not necessarily involve engineering transactions. Their purpose is to make manifest the general principles of the law. Following the cases are short excerpts from decisions in cases involving engineering transactions, or such transactions or situations with which an engineer is likely to meet.

It seems to us that this method of treating the subject is an excellent one. It combines the textbook method with the case system, and after inculcating general principles, which is the most important object of any course of law study, additionally gives, in the briefest form, a body of legal information of particular value and interest to the engineer; in other words, illustrates the broad general reasoning of the law by application to circumstances peculiarly familiar and interesting to the student. P. T.

Partial Report Upon the Comprehensive Plan for the Collection, Purification and Disposal of the Sewage of the Entire City (Philadelphia). Report of the Bureau of Surveys, 1910. From Mr. Geo. S. Webster, Chief Engineer and Surveyor. Boards, 6 by 9 in. 204 pages; many illustrations.

This book is an important contribution to the literature of Sanitary Science, as describing particularly the "operation at the Sewage Experiment Station at Spring Garden, Philadelphia," carried on by the Department of Public Works.

The opening of the book shows the Authorization by City Ordinance for the Department of Public Works to make investigation and report upon a comprehensive plan for taking care of the sewage of the entire city. The ordinance provides for a "Comprehensive Plan"; for "Alteration and Extension of the existing sewer system"; for "Experiments and Report on the Treatment of Sewage"; "Estimates of the cost of altering the present sewer system"; "Constructing Intercepting Sewer System, etc.," and "Maintenance of Disposal Works."

The experiments and reports on the treatment of sewage is the particular matter of this report. When the reports covering the other parts of the city ordinance are published, the collection will be of great value to the sanitary engineer.

A Summary of Conclusions is presented which is valuable, and is based on the detailed results of the full reports. This covers the subjects of Screening, Sedimentation with Horizontal and Vertical Flow, Slate Contact Beds, Sprinkling Filters, with sub-head of distribution, rate of operation; Media, kind, size and depth of bed, etc., disinfection, dilution, sludge, the amount, condition, disposal, etc.

There has not yet been found a means of avoiding a collection of sludge if purification is to be effected. Whether the amount of sludge is more or less, and the amount varies with the character of the raw sewage and also with the manner of purification, yet it is always a troublesome matter to dispose of it. One experiment reported in this book is the mixing of the sludge with fine (rice) coal, which assists in drying out or absorbing so much of the water that the mixture could be removed from the sludge bed in a day and could be successfully burned. From the porous character of the fine coal there was a better elimination of the water, and the coal itself was a considerable aid in combustion. Other experiments were made on sludge with about 85 per cent. to 95 per cent. moisture which was pumped into lagoons, or basins, dug in the earth and where the sludge was dried by evaporation from the surface and also some water was absorbed by the earth bottom of the lagoons. Of course such drying of the sludge was influenced by atmospheric conditions. But the results of these many experiments upon drying the sludge are very interesting. There are many other good things in this "Partial Report" worthy of the attention of the sanitary engineer.

W.

LIBRARY NOTES

EXCHANGES.

New Hampshire Railroad Commission:
  Sixty-sixth Annual Report, 1910. Cloth.
Massachusetts Board of Gas & Electric Light Commissioners:
  Annual Reports, 1902-1909, inclusive. Paper.
New York Public Service Commission, Second District:
  Third Annual Report, 1909. Vols. I and II. Cloth.
Tennessee Geological Survey:
  Preliminary Study of Forest Conditions in Tennessee. Pam.
  Bulletin 13, The Resources of Tennessee. Pam.
Engineering Association of the South:
  Proceedings, Vol. XXII, Jan.-Mar., 1911. Pam.
Colorado State Bureau of Mines:
  Report, 1909-10. Pam.
John Crerar Library, Chihcago:
  Sixteenth Annual Report, 1910. Pam.
National Society for the Promotion of Industrial Education:
  Bulletins, 2, 3, 4, 5, 6, 9, 10, 12, 13. 12 pams.
Royal Scottish Society of Arts:
  Gas Manufacture and Lighting. Pam.
Institution of Civil Engineers, London:
  Proceedings, February, 1911. Pam.
International Navigation Congress:
  Proceedings of Congress at St. Petersburg, 1908.
Ohio Geological Survey:
  Bulletin 12, The Bremen Oil Field. Cloth.
Canadian Society of Civil Engineers:
  Report of Annual Meeting, 1911. Pam.
  List of Members, By-Laws, etc., 1911. Pam.
Canada Department of Public Works:
  Report of Precise Leveling Georgian Bay Ship Canal Survey. Cloth.
  Report on Georgian Bay Ship Canal. 1908. Cloth; 3 boxes plates.
  Ottawa River Storage, Progress Report, 1909-10. Supplemental to Report on Georgian Bay Ship Canal. Pam.
Armour Institute of Technology:
  Bulletin, May, 1911. Pam.
Maine Commissioner of Highways:
  Sixth Annual Report, 1910. Cloth.

GOVERNMENT PUBLICATIONS.

Department of Commerce and Labor:
  Pilot Rules for Various Inland Waters of the U. S. 4 pams.
Interstate Commerce Commission:
  1st, 2d and 3d Annual Reports of the
  Block Signal and Train Control
  Board, 1908-9-10. 3 pams.
Isthmian Canal Commission:
  Reports of Isthmian Canal Commission, 1904-10 incl. Paper.
  Canal Record, Vols. II and III. Cloth.
U. S. Coast and Geodetic Survey:
  Report of the Superintendent, 1910. Cloth.
U. S. War Department:
  Tests of Metals, 1909. 3 vols.; cloth.
U. S. Commissioner of Corporations:
  Taxation of Corporations, Parts I and II. Pams.
  Report on the Beef Industry. Pam.
  Report on the Transportation of Petroleum, 1906. Pam.

May, 1911.

Report on the Petroleum Industry, Parts I and II. Pams.

Department of Agiriculture:

Report on the St. Francis Valley Drainage Project in N. E. Arkansas.

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ADDITIONS TO MEMBERSHIP.

P. W. Leisner, Evanston, Ill	Member
John C. Pinney, Milwaukee, Wis	Associate Member
John C. Gustafson, transfer, Junior to	Associate Member
Walter C. Douglas, New York	Junior Member
H. W. Rutherford, Chicago	Associate Member
E. S. Pennebaker, Chicago	Junior Member
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Stanley V. Meigs, Pueblo, Colo	Junior Member
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Julian B. Freeman, transfer from Junior to	Associate Member
Meyer Fridstein, Chicago	Member
Edward H. Bangs, Indianapolis, Ind	Member
Frederic R. Charles, Richmond, Ind	Member

DEATHS.

H. A. Rust, Hinsdale, Ill	February 5, 1911
William B. Ewing, Chicago	April 8, 1911
A. D. Page, Chicago	April 7, 1911
Jewett N. Darling, Colton, Cal	April 22, 1911

Journal of the

Western Society of Engineers

VOL. XVI JUNE, 1911 No. 6

THE ILLINOIS ENGINEERING EXPERIMENT STATION IN ITS RELATION TO THE PUBLIC*

W. F. M. Goss, M. W. S. E.

Presented March 15, 1911.

The Engineering Experiment Station of the University of Illinois, now just entering upon the eighth year of its existence, was organized for the purpose of conducting investigations of importance to professional engineers and to the manufacturing, railway, mining, and building interests of the state. In presenting the results of its work, the Station has thus far printed and distributed forty-four bulletins. The reception accorded these publications has been altogether complimentary to the work of the Station. Many engineers in receiving its bulletins have certified to their stimulating and helpful influence, and others have spoken of benefits derived from them by the industries they represent. The value of the work of the Station to the technical interests of the state having thus been attested, it is my present purpose to consider the extent to which its work affects the welfare of larger classes of people; to inquire as to whether, on the whole, its work is a matter with which the general public may be concerned.

Before attempting to answer this question, I must call attention to certain influences which tend to augment the interest of all civilized people in the work of the engineer; to the changes in occupation which are steadily increasing the percentage of persons in every community who directly or indirectly depend for their support upon engineers. It was not long ago, if we count by generations, when the founders of our nation began their work. They came to a world which was new, not merely by virtue of its recent discovery, but because in all its natural resources it was fresh and untouched. Its forests were virgin. Its prairies and plains were rank with the wild exuberance of their vegetation. Its streams spread themselves quietly over broad areas or ran boisterously on

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*In a paper published in the JOURNAL of this Society for August, 1909, Dr. L. P. Breckenridge, at that time the Director of the Illinois Engineering Experiment Station, discussed the work of the Station in its relation to Illinois industries. His paper should not be overlooked by anyone interested in this phase of the general subject. It is the purpose of the present paper to extend the discussion so ably introduced, by the presentation of another aspect of the Station's work.

their unfettered way to the sea. Its mineral resources were undisturbed and for the most part unknown. Into the midst of all this wealth of natural resource came the representatives of civilized society, with a determination to build homes. Others came, until by immigration and by natural increase there was developed a nation of people. The pioneer was of necessity concerned with agriculture, but as people multiplied, the desire for trade appeared, and this in turn led to the construction of roads and to the introduction of other means of transportation. Men gradually drew upon distant parts for portions of their support, luxuries became necessities, until today no one is so poor as to be limited in what he has by that which he, himself, is able to produce.

Progress in this direction has given rise to other occupations than agriculture, because conveniences and luxuries are matters which must be paid for in labor, and labor absorbed in manufacture cannot be available for the cultivation of the soil. This steady transfer of men from the farm to the business office or factory has not taken place because the farm has been unattractive, but chiefly because all classes of people, including farmers, have desired things which contribute to their convenience and which can only be supplied as the result of non-farm labor. It constitutes an important factor in the process by which the United States has taken its place among the nations as the largest producer of fuels and metals, the possessor of the greatest mileage of railroads, and the most ingenious and efficient of manufacturers. From being a nation of agriculturists we have become a nation in which the engineer flourishes, and in which a large percentage of all the people find their vocation in fields that have been developed through scientific and technological research. The fact that the process of farming has been so developed that the amount of manual labor required to produce a bushel of corn has steadily diminished, has perhaps aided and otherwise encouraged the transfer. This process of change affecting the occupations of men, which has been nationwide in its scope, has had a pronounced effect upon the people of our own state. Illinois but a few decades ago was strictly an agricultural state. It is now not only a great agricultural state, but a great manufacturing state as well. Today only a little more than one-fourth of all the people in Illinois depend upon the soil for their support, while fully half of all depend upon the manufacturing, mining, and transportation industries, and the value of our state's manufactured products has grown to be four times greater than the value of its agricultural products.

These facts imply that a large and constantly increasing percentage of all the people of our state live in an atmosphere of engineering activity, and that their happiness and success in life depend in large measure upon the successful direction of the activities with which they are concerned. Any process of general education, to be effective, should take account of the changing conditions under which the people who are to be benefited, live, and any great movement, such as that represented by the activities of the Engineering Experiment Station, which has for its purpose the betterment of a state's industries, necessarily becomes an important factor in the education of large numbers of its people.

For example, it is one of the functions of the Station to supply information of value to manufacturing, mining and transportation interests. Whatever service it may render in increasing the efficiency in the operation of any single establishment, increases the stability of that establishment as a going concern, and gives increased security to its employees. Moreover, increased efficiency, whether obtained through the adoption of new devices, or of new methods, or through the application of more advanced principles in design, involves at some point, a higher order of attention; it implies an elevation in the character of the service and ultimately a higher order of work for those employed. In so far, therefore, as the researches of the Engineering Experiment Station benefit the manufacturing, mining, and transportation interests of the state, they will not fail ultimately to affect favorably that half of the state's population which derives its support directly from these industries.

Again, the factory, the mine, and the railroad serve and draw their support from the public. In the long run, whatever helps the manufacturer becomes available to his patrons, and whatever contributes to better railroading ultimately increases the comfort or convenience of the traveling public, or shortens the time during which merchandise must remain in transit, or lowers the cost of its transportation, or contributes to all of the results combined. A letter recently received from the chief engineer of a great railway operating out of Chicago acknowledges the indebtedness of his company to the Engineering Experiment Station. He writes:

> "I know from my own personal experience that the research work of the University along the lines of reinforced concrete construction has been of incalculable value to this company, which has spent many hundreds of thousands of dollars for such construction during the past few years. The data developed by the work at the University have in large measure made it possible to employ this more economical form of construction, notwithstanding its newness, with full assurance that the ultimate result would be entirely satisfactory."

This generous acknowledgment emphasizes a benefit which doubtless has been enjoyed, to a greater or less degree, by other railroads. As a result of the scientific processes of the Station, men in charge of large undertakings have received suggestions leading to more economical design, and they have been willing to adopt such designs because of assurances supplied them in the results of the Engineering Experiment Station. It is worthy of notice that the contribution of the Station is not merely a contribution to a chief engineer of a railroad, or to a great railroad corporation, or to all the railroad corporations of the state, but in a large sense it is a contribution to all the people of the state, who sooner or later pay for the improvements which the railroads make, and who derive benefit from the increased facility which their improvements permit. Again, if it should be possible for the Station to show, to the satisfaction of the mine operators of the state, the value of a proposed improvement in mine operation, whereby the mine wastes may be reduced and the output per man increased, and if by its demonstrations it can convert the mine workers to the better practice, the immediate benefit would, of course, be to those concerned with the business of mining and their dependents, but the ultimate effect would be to reduce or to keep down an increase in the cost of fuel,—a benefit in which all consumers of coal would share.

Without attempting further to embellish the argument, it will, I believe, be admitted that any industry to which the Engineering Experiment Station of the University of Illinois makes a contribution in the form of a scientific fact, becomes of necessity a distributing agent through which the fact is made serviceable to the public, and that as a consequence the Station, through the exercise of its legitimate functions, makes a contribution to the life and the welfare of all classes of people.

In the preceding discussion, I have regarded the Engineering Experiment Station only as an organization for the development of scientific facts or technical rules of procedure. It is in truth much more than this; it also constitutes a great educational movement. This has a twofold aspect:

First, it develops and distributes information to the general reading public. Its publications, each one of which, if it serves its full purpose, discloses a distinct advance of the art in the field it represents, are widely distributed. They reach not only those who are in a position to profit at once by them in a practical way, but many others who through their appreciation of such matters welcome them as a source of useful information. The bulletins serve to quicken their intellectual activities, to stimulate their imagination, and to increase their understanding of things which are technical. This phase of the Station's work in the midst of a people whose daily lives are spent in close association with engineering activities, constitutes a form of educational extension work which loses nothing in value by being highly specialized.

The second aspect of the educational value of the work of the Station is that which is made manifest upon the campus of the University. The work of the Station proceeds hand in hand with the instructional work of the College of Engineering. The students of the College, whose activities are necessarily largely absorbed by the demands of the class room and by the routine work of the various laboratories, have contact with the more advanced work of the Station, which is helpful to them. They have acquaintance with the men who are doing the work of the Station, from some of whom they receive instruction. Through a common personnel, the activities of the Station are reflected back to the class room, and nothing stimulates the interest of students so much as the presence in the class room of an instructor who is known to be doing something to advance the practice of the profession which he teaches. The investigations of the Station are carried on in the laboratories of the College. While the student works at his routine tasks, his professor works beside him upon problems of greater significance. The student may not understand all that he sees, but the activities of his professor create an atmosphere of industry which exerts a strong and wholesome effect upon him.

Closely related to the benefits derived by University students through the activities of the Station, are those which accrue to the professor. No man can long continue to give himself to work of instruction, unless he also gives himself systematically to the task of acquiring information. The opportunities for doing this, which are presented to the members of the instructional staff at the University of Illinois through the activities of the Station, are greatly prized by those who profit by them. Young men in training for responsible positions as instructors, find no process more effective in their development than that of the research laboratory, while those who are more experienced, find in the facilities of the laboratory means by which they can turn their experience to useful account. These are significant facts. In my opinion, they justify the belief that the Engineering Experiment Station would be worth all it costs if maintained merely as a coördinate branch of the educational work of the University, solely for the benefit of the students upon its campus. If it were necessary to do so, one might disregard the value of the Station's contributions to the industries of the state and through them to the public in general, and justify its activities entirely on the ground that they serve to raise to a higher level than would otherwise be attained, the University work of both professor and student.

It is clear that the value of the Station is not entirely to be seen in the publications it has produced; nevertheless, they form a fair index of its activities, and brief reference should be made to them. There have been issued at the time of this writing forty-four different bulletins in editions varying from 3000 to 12,000 copies. One bulletin has been through two editions of 10,000 copies each, and it is now out of print. During the last three years there have been issued each year by the Station approximately 5,000,000 pages of printed matter. The distribution since the establishment of the Station totals 18,000,000 pages. Of the forty-four bulletins which have thus far been issued, sixteen have dealt with some phase of the recently developed art of reinforced concrete, or with investigations concerning the physical characteristics of other building materials. Fifteen bulletins have presented the results of studies concerning the utilization of fuel under steam boilers, in house-heaters, and in gas producers, or have dealt with more abstract problems involving the composition of fuel and their behavior under prescribed conditions. Three bulletins have dealt with electric lighting problems, two with the art of metal cutting, two with a system of filing engineering literature, and a number of individual bulletins have presented the results of less extensive investigations. As my personal connection with the Station has been brief, and as its achievements to date have been chiefly due to the efforts of others, I may properly add that the value of the work done is attested by a voluminous file of letters originating in every part of the state of Illinois and in many parts of the civilized world.

In the further development of the work of the Station, following the precedent already established, an effort will be made to define certain broad lines of research, the pursuit of which will disclose the nature and extent of the specific investigations which should be undertaken. At least two such lines have already been established, namely, that of fuel production and utilization, and that which is embraced by a study of the physical properties of the materials of construction, including the application of reinforced concrete. Other broad lines which should be entered upon in the immediate future are:

1. The utilization of electricity, especially in its application to lighting and to the agricultural, metallurgical, and manufacturing arts.
2. Gas production and utilization in the development of power.
3. Transportation problems.
4. Pneumatics and Aëronautics.

The rapidity with which the Station can proceed along the lines to which it is already committed, and the extent to which it will be possible to take up new lines must, of course, depend upon the extent of the support granted by the Legislature.

In addition to these more formal lines of action, there are now and always will be in progress a considerable number of minor investigations which have their beginning in the work of students whose theses are based upon experimental investigations. Results which are thus made available are frequently of real value to the Station, or they are of such a character that they may be made of value by some extension of the initial research.

Thus far, the Station has concerned itself only with investigations which have been highly scientific, the results of which are assumed to have the widest possible application. The question has been raised as to whether the Station may not enlarge its scope by adding to its present functions, work leading to the solution of purely commercial problems, the results of which would be of immediate value only to some particular individual or group of individuals. For example, a manufacturer presents a new type of machine with the statement that it is patented, that he expects to build and to sell such machines, but that before going heavily into the business of its manufacture he must have reliable information concerning its practical efficiency. Will the state, acting through the Engineering Experiment Station, test his machine? Under the policy which has thus far controlled, the Station declines so to do; it cannot employ public funds to assist a private enterprise. The manufacturer, however, meets this objection by offering to reimburse the Station for all its outlay. He will do more than this; he will gladly accept an accounting which will return a profit to the Station, and he urges that, since he is prepared to pay the costs, the state should not withhold from him the use of facilities which are not available to him elsewhere, or the services of investigators who are especially qualified to serve him. He argues, also, that the freedom of the Station from all business entanglements qualifies it to serve him as an independent expert in a manner which gives peculiar value to the results obtained. In this manner there is introduced a question involving the activities of the Station, which thus far has been studiously put aside. Whether the Station is right in ignoring such appeals, or whether it will ultimately yield to them, are, of course, questions for the future. It is, however, clear that the Station should not enter into competition with existing commercial laboratories, but the fact should be recognized that the Station has some advantage over these laboratories in the extent of its equipment and possibly, also, in the quality of its experts. It is, therefore, not impossible that there may be a field in commercial testing, outside of and beyond that covered by the commercial laboratories, into which the Station could properly enter, but the limitations which should be applied are difficult to define.

Among the lesser problems of the Station of especial interest to the public, is that involving the distribution of its bulletins. In the beginning of the Station's work, several different lists were established. For example, one list contains the names of civil engineers, builders, contractors, etc., and another the names of steam engineers, boiler manufacturers, and coal operators. By the practice of the Station, a bulletin on reinforced concrete was sent to those of the first list and not to those of the second, while a bulletin on the burning of Illinois coals without smoke was sent to the second list and not to the first. Experience has developed some difficulty in maintaining the distinction necessary to satisfactory operation under this plan. A man who is on the first list, and who as a consequence gets all the bulletins sent to that list, may see a notice of a bulletin which was not sent to him or to any one in the group to which he belongs, and the notice may interest him. He wants the bulletin and he cannot understand why he has not received it. Again, among those who receive bulletins are many who preserve their files and some who bind them. The bulletins are numbered serially. When such persons look over their stock and discover that their series is incomplete, they want the missing numbers and they sometimes assume that it is through some defect in the management of the Station that they have not received them. Under such influences as these, there has been a constant tendency to extend the list of those who are to receive all bulletins, at the expense of the specialized lists, all with a strong probability that the ultimate solution will be found in the maintenance of a single list. Such a plan, however, implies larger editions and greater cost for printing, and with the present limited resources, smaller sums for the prosecution of actual work of research.

The fact that the distribution has thus far been entirely gratuitous has opened the way to minor difficulties. For example, book dealers and news agents, both in this country and abroad, frequently have calls for bulletins, the existence of which have become known to their customers through the publication of press notices. But such dealers will not handle publications which are distributed gratuitously, for with no price there can be no commission, and their customers, who might become friends of the Station, go unsupplied. Again, as the stock of a particular bulletin on the shelves of the Station approaches exhaustion, it is extremely difficult for the Station to determine who among the subsequent applicants, are most worthy to become the possessors of the few remaining copies. The importance of a price applicable to all alike at this stage of the process would be of great assistance in eliminating the unworthy inquirer and would operate in the interests of the seriously disposed applicant. Influenced by such considerations as these, the Trustees have recently authorized the fixing of a price upon all bulletins of the Engineering Experiment Station. Such action is not intended to abridge the privileges of those who hitherto have regularly received these bulletins without charge, for each bulletin as issued will, as heretofore, be subject to an initial gratuitous distribution on the basis of the existing list. But in addition to this, the bulletins will be placed on sale at the price stated, both in this country and abroad, and it is probable that as the supply of any issue approaches exhaustion, it will be withdrawn from the list of those which are available for free distribution. It is hoped that these provisions will operate to increase the usefulness of the Station.

In that which has preceded I have discussed the work and problems of the Engineering Experiment Station as an independent entirety. I desire now to emphasize the importance of its organic relations to the College of Engineering, the exclusive purpose of which is to train men for the profession of engineering. The Station is dependent upon the College in many important respects. It is not a rival of the College. It cannot be permitted to grow at the expense of the College; it can only prosper as the College develops and prospers. The funds as appropriated by the Legislature are designated as for "the maintenance and extension of the College of Engineering and for the expenses of the Engineering Experiment Station". The financial interests of the two organizations are, therefore, held in common. The heads of departments of the College are *ex officio* members of the directing staff of the Station. While I am clear that occasions will arise when it will be desirable to call to the aid of the Station the services of outside experts to serve under pay for brief periods or during the progress of some specific work, the immediate direction of the activities of the Station must always rest with the professors of the College. The inspiration which is to keep the researches of the Station upon a high plane far in advance of current practice, if possessed at all, must be supplied by the professors of the College. The Station thus far has been fortunate in having commanded the services of rare men. They have been and are still the leaders in the work of the College, and it is important to the success of future undertakings that the organization of the College be developed in advance of the requirements of the Station. Men are more important initially than either plans for work or organization. The first requisite, therefore, in the further development of the Engineering Experiment Station, is to secure increased strength in the faculty of the College of Engineering.

The Engineering Experiment Station is dependent upon the College for the laboratories in which its work proceeds, and for much of the equipment which it uses. The joint use of laboratories and equipment by the Station and College constitutes an arrangement which makes for the efficiency of both organizations, and it should always continue. Equipment which, if purchased for the instructional work of the College alone, would be used but a small portion of the total time, may through this arrangement be of service in the researches of the Station, and its use by both interests makes for high efficiency in the utilization of apparatus and of laboratories. It should justify having for the work of the University, facilities of exceptional quality.

The College of Engineering and the Engineering Experiment Station are in urgent need of buildings. Except for the department of Physics, which is an organic part of this College, it has received no appropriation for buildings since 1894. In this period of sixteen years the number of students has increased more than fourfold, the courses of instruction offered have greatly multiplied, and the Engineering Experiment Station has been added. The whole organization has grown from one of less than 300 students and 23 instructors to one of more than 1300 students and nearly 100 instructors, and the variety of its activities has increased in like proportion. Meanwhile, the addition to the area of floor space available has been slight,—only such as has been secured from the use of comparatively small amounts saved from sums appropriated for maintenance. As a result, the work of all departments is seriously affected by limitations arising from lack of room. There are especially needed a materials testing laboratory and a transportation laboratory.

The materials testing laboratory now occupies a portion of a comparatively small building. Operations supplemental thereto, such as the making of concrete beams and columns for test, and such as are incident to the work of the cement laboratory and of the road materials laboratory, have already been crowded out of the main laboratory and are carried on elsewhere. Quarters which once were ample, have now become entirely inadequate. The equipment is crowded to a point which makes its operation difficult. The number of students to be accommodated is greater than can well be received, and the work of the research, which naturally awaits the attention of the laboratory, demands facilities that are not now available. The value of the work already accomplished by Professor Talbot in this field may be accepted as evidence of his ability to make of service to the state any enlargement of the facilities which may be placed at his disposal. The proposed laboratory should have an abundance of room for the preparation of materials; it should contain a large amount of duplicate apparatus for the convenience of students; it should have a few machines of such capacity as will permit the testing of full-sized building or bridge members; it should provide means for determining all the physical properties of steel and other metals, of concretes, of woven fabrics, of paper, and of such other materials as paints, oils, and lubricants; it should be so equipped that physical tests may in special cases be supplemented by chemical investigations; and there should be an abundance of yard room to permit the storage of bulky materials, to give space for tests to determine the weathering qualities of materials, and to admit of the construction of temporary and experimental structures of various kinds. The possession of such facilities would give the College of Engineering opportunities to which it is fairly entitled by the high character of the work already accomplished.

The University of Illinois more than any other institution in the country, has developed courses of instruction especially planned to prepare men for service with railroad companies. As yet it has done little in contributing to the sum of scientific information for the use of such companies. Complete success in dealing with the transportation industry requires that the work of instruction already undertaken by the University, be accompanied by work of engineering research. The facilities needed for research are necessary to the proper instruction of students, and the results of research constitute important factors in the establishment and maintenance of helpful relations between the College and the great transportation companies of the state and country. The field for research is that which underlies the design, construction, maintenance, and efficiency of structures and machines peculiar to the railroad service. The transportation laboratory must deal with the problems of track and of track structures as well as with those of the locomotive and cars. A central feature of the laboratory portion of the proposed new building must be a testing plant upon which a full-sized locomotive, either steam or electric, can be mounted and operated for an indefinite period, under any prescribed condition of speed and load. The laboratory should actually possess a steam locomotive which would at all times be available for use. In addition to the locomotive testing plant, the laboratory should supply a place for the test-cars now owned by the University, and provide facilities for mounting them for such work involving their use as cannot be done on the road. Similarly, the brake-shoe testing machine, recently completed, and the drop testing machine which was finished last year for testing rails, axles, and couplers, and other plants especially designed to serve in investigating various details entering into the construction of cars or locomotives, should be given a place in this laboratory. With these more important plants, the transportation laboratory should contain typical installations of all necessary equipment used in the construction of track and upon cars and locomotives, such as switches, frogs and rail joints, air brakes, couplers and draft-gears, locomotive valve gears, boiler feeds and sanders. Such apparatus when of simple construction would merely be given a place as permanent exhibits, but whenever its nature permits, it should be installed in such manner as will allow its action to be studied and its efficiency under service conditions, to be determined. A laboratory thus established and equipped would, in common with the other advanced laboratories of the College of Engineering, serve the double purpose of providing for the instruction of students and as a means of research. The College is already committed to the training of men in the several engineering departments of the railroad; but the full fruition of this purpose can appear only in the development of such a transportation laboratory as I have outlined. The time is now opportune for such a development.

I make no apologies for detailing in this presentation the urgent needs of the College of Engineering and of the Engineering Experiment Station, for their welfare constitutes a great public question of interest not only to the engineering profession, but to all the people of the state. It has been largely through the influence of members of this Society that the upbuilding of the College has been secured. It was largely through the interest of members of this Society that the Engineering Experiment Station was established, and the Society as a whole has in many ways shown its appreciation of the work which the Station has thus far done. You will, I am sure, agree that the enthusiasm, with which you regard the work of the Station, should now stimulate you to do what may be done in giving effective support to plans for the further development of both College and Station, to the end that the work of the engineers of this great state may be further dignified and improved.

DISCUSSION.

W. L. Abbott, M. W. S. E.: One great need in engineering education is to keep students and instructor in touch with real practical problems during the period that the greater part of their time is occupied in studying the theoretical principles which underlie engineering science. Various expedients are used to fill this want, but none to my mind fit in so well with regular college work as does the work of the Engineering Experiment Station. Here, as Dean Goss points out, real, live, practical problems are attacked and solved, and the resulting information is used to correct or to verify the theories which have guided the engineer in applying the principles involved.

Illinois spends annually two billions of dollars in lines of work which command the attention of the Engineering College, and the Engineering Experiment Station.

It does not seem improbable that better engineers, prepared in the Engineering College, together with newer principles, developed in the Experiment Station, might effect a saving of one per cent of the annual outlay above referred to, and yet if this were done for a single year, it would save for the business interests of the state a sum equal to the entire amount which has been expended on the University since it was founded.

W. E. Symons, M. W. S. E.: I have listened with much interest to the very instructive address of Dean Goss on the work of the Engineering Experiment Station at the University of Illinois, and particularly its relation to the public. Both the address and the lantern slide views emphasize the importance of this branch of the University work, and should, I feel, serve to arouse those not already in sympathy with the movement, to a full realization of its value, and the necessity of liberal support.

Aside from the information contained in this paper, with respect to the work of the Experiment Station, I am glad to be able to state that the bulletins issued from time to time have been of more than ordinary value to me.

Some two years ago, while connected with one of the railways running out of Chicago, but with offices in St. Paul, the question of contracting for locomotive fuel was up for disposition. The road used about 600,000 tons of coal per year, the supply coming from the Illinois field, and for immediate use in that matter I wanted an analysis of the coal in question. Turning to my files of bulletins issued by the Station, I found just what was wanted, and that much more complete and accurate than the railroad company could have prepared, even had it been attempted. This, of course, is only one instance but there are doubtless scores of cases wherein the work of this Station has been of incalculable aid and value to railways, industrial concerns, the farmer, the merchant, and the community at large.

The Mississippi Valley will eventually be the home of 150,000,000 people and Chicago the home of 5,000,000 people. The railways of the United States have an estimated value of over $16,000,000,000, and it is claimed by the highest authority that they are now and for some time have been in need of additions and improvements in the way of double tracks, additional yards, and side tracks, new and enlarged terminals, additional cars, locomotives and electrification at certain points where feasible, to an amount of over $10,000.000,000, and with twenty-six railways entering Chicago, it can readily be seen that the engineering problems to be solved in the future in Chicago and in the state of Illinois are of stupendous proportions. This should prompt every loyal, patriotic citizen of the city or state, and particularly the members of this Society, to give such support to our educational institutions, especially the Experiment Station at the University of Illinois, as will insure ample facilities for promptly meeting any and all demands in solving these problems, many of which now confront us.

Albert Scheible, M. W. S. E.: To those familiar with the practice of other technical colleges, both in the east and the west, it is particularly pleasing to note the unusual attitude reported by Dean Goss in regard to declining pay for tests or experiments made for manufacturers. In so many other institutions this undertaking of commercial tests has long been common practice, without which those in charge of the laboratories would not receive anything even approaching an adequate compensation for their trained services. The result is that instead of devoting all of their time to instruction and to disinterested advancement of their lines, considerable of it goes into this commercial work. Or, if this testing and the like is turned over to students who have had little or no training for it, the results are not always reliable; indeed, I know of cases where whole series of tests nominally made by men of high standing had to be ignored and repeated by regular testing laboratories, because the students engaged in the tests did not have an adequate grasp of the problems involved. In either case, such uses of the college laboratory facilities (which are rarely adequate even to the needs of the school itself for instruction purposes) tie up part of the equipment which the institution has provided for the use of its students, thereby hampering their progress. Those in charge should not be blamed for this as long as they have to look to such outside work for any considerable part of their income. But it is refreshing to note that the state of Illinois is making its engineering experiment faculty independent of such outside earnings so that their whole time, together with the whole of the equipment provided for them, can be used disinterestedly for instruction purposes and for any tests or researches that may be of general interest.

June, 1911.

A. Bement, M. W. S. E.: For several years, I, as a representative of the Society, have been one of a committee having to do with the work of the Experiment Station. I am greatly interested in the work of the Station, and in connection with what Mr. Abbott has said regarding the Station, it may be well to say that the Experiment Station, like the Geological Survey, is located at the University for reasons of convenience and economy. By operating the Experiment Station in connection with the University, it is possible to utilize the same equipment and people for both the University and the Station. This makes unnecessary the duplication of apparatus, plant, and buildings, as well as of people, which would be necessary if the Station was operated independently. This may be illustrated by the case of the Geological Survey, which has, for example, its chemical work done by and in the laboratories of the University, and in other ways has assistance which tends to economy and convenience in the execution of the Survey's work.

The Illinois Engineering Experiment Station is, I believe, the first institution of its kind to be established, and, as Dean Goss has indicated in his paper, there is a question as to what kind and character of subjects it should accept for investigation. To me it seems that the answer is not an easy one; in fact, I consider it rather difficult. There are, however, two lines along which I should very much like to see investigation proceed.

First, that an effort be made to take up neglected but obviously meritorious propositions, or, in other words, that the Station investigate and report upon those things, which, while neglected, have recognized merit.

Second, that it act as what may be called a court of final resort. In this connection it is probable that important service could be rendered the community in the elucidation and clearing up of uncertainties in engineering practice. Frequently, such problems have very great economic significance and the advantage of a correct solution is sometimes very important.

DYNAMICS OF THE FLYING MACHINE.

James S. Stephens, M. W. S. E.

Presented April 5, 1911.

It should be understood that while it is the writer's belief that this paper contains a plausible theory to account for some of the dangers of mechanical flight, he hopes it will be chiefly instrumental in interesting some of the engineering profession who have heretofore given the matter little serious thought or attention; also that it may promote a discussion of some of the phases of the question and thus bring out information that may assist in the advancement of the art.

The writer is aware of the fact that some of the statements and deductions made herein, when considered from certain view points, are not in accord with the laws of dynamics as ordinarily accepted, but this should aid rather than prevent a liberal discussion, as some of the peculiar conditions involved may cause the majority of those who consider the matter to at least question the exactness of some of the laws of dynamics as commonly understood, when applied to the operation of a flying machine.

During the past decade, public opinion of the flying machine may be said to have passed through three stages.

First, viewed as ridiculous, then as sublime, and now, on account of the great number of fatal accidents which have occurred, as tragical.

All of these accidents have had some specific cause, and numerous explanations and theories have been offered to account for them. Unfortunately the man who would have best been able to offer a satisfactory solution has in practically every case lost his life.

Theories have been advanced by some of the aviators blaming the so-called *Swiss cheese* sky and *holes in the air* for many of these accidents.

It is generally admitted that there are many varying currents in the air, and that these changes of speed and direction in the motion of the air are undoubtedly greater near the surface of the earth than they are higher up, and while some of the difficulties of flying are chargeable to this cause, it has, the writer believes, been blamed for a great deal more than it is accountable for. Such variations as do occur in the trend of the wind or air currents are not sufficiently abrupt to make flying extra hazardous from that cause alone.

Once a machine is off the ground, it would be immaterial whether the wind was blowing steadily in one direction one mile or one hundred miles an hour, if it were not for the fact that it is necessary to give due consideration to the laws of inertia, acceleration, retardation, momentum, centrifugal force and gravity in their proper relation to the speed of the machine, both relative to the air and relative to the earth.

The writer will not undertake to discuss in mathematical detail these various factors governing the conditions of mechanical flight, but will confine himself to some simple illustrations which he believes will provide an explanation of the causes of many of the aeroplane accidents which have lately happened.

In still air a flying machine, in maneuvering in a horizontal plane, would have to accommodate itself to practically the same conditions as a vehicle on the ground. In starting up, increasing or decreasing the speed, the inertia of the weight of the machine must be overcome, thus introducing the elements of time and power. In turning, some positive resistance, such as banking the machine, must be depended upon to counteract the centrifugal or tangential forces.

All of the men who have flown these machines have learned to do so in comparatively still air, and have been thoroughly familiar with the conditional requirements just referred to, as a result of their experience with vehicles running on the ground.

Flying in a wind, the writer believes, introduces the effect of some of Nature's laws in a way that up to the present time has not been fully appreciated, and therefore has not had the consideration which is due.

To illustrate, imagine a machine flying at the rate of 40 miles an hour, which is in round numbers 60 ft. per second, directly against a wind blowing at the same speed. While such a machine would maintain itself in the air just as surely and safely as if it were flying on a calm day and covering a distance of 40 miles an hour as measured on the earth's surface, it would in fact actually be standing still, in so far as its relative position to the earth is concerned, and the entire output of its engine would be expended in supporting it against the action of gravity and preventing it from drifting backward in the wind.

Now, for the sake of the illustration, consider what would happen if the 40-mile wind could be suddenly stopped. The machine, having no initial velocity or momentum, could get no support from the air until it could acquire a sufficiently high relative velocity. This, on account of inertia, and the limited power available, requires time, and during such time-interval, the machine must fall. While the abrupt stopping of a 40-mile wind is not possible, a somewhat analogous condition may be brought about by an abrupt turning of the machine when it is stationary relative to the earth through flying against a high wind as above mentioned.

Under the most favorable conditions, it would take considerable time to bring a machine weighing about 1,200 lb. from a standing position up to a speed of 60 ft. per second, or double this speed, as the writer will endeavor to show may be necessary under certain practical conditions.

The following is quoted from *Aircraft,* the December issue, describing the flight of Johnstone and Hoxsey at the Belmont Park International Aviation Meet, both of whom have since lost their lives as martyrs to the cause of progress. "They faced the wind coming in from the ocean, and as they went higher their speed in relation to the ground rapidly diminished as that of the air they were meeting became greater. Soon they appeared to be standing still, the velocity of the wind being just even to theirs (about 38 miles), and then, as they went higher, they started to lose ground and the higher they went the faster they went backwards. Close together they appeared like two great kites on a string—a string being slowly paid out."

How great a wind Johnstone faced at his maximum altitude of 8,500 ft. no one can say, but with his machine going close on to 40 miles an hour, he was blown backwards some 40 miles in the course of less than two hours, and 75 miles an hour is not an exaggerated estimate of the maximum velocity of the wind met by him.

Brookins, Johnstone, and Hoxsey on Wright machines have made complete circles in the air in about six seconds. Let us suppose one of them had undertaken to make such a turn when flying against a head wind; a quarter of a turn would be made in less than two seconds with the result that, whereas the machine before the turn had the necessary supporting power to maintain it in the air, in less than two seconds of time it would have turned around a quarter of a turn in the air, and with respect to its relative position to the earth, would have practically turned upon its own center, and have begun to drift sideways, having practically lost all of its sustaining power; it had no initial forward motion when commencing to make the turn, the time allowed not being sufficient to acquire the necessary acceleration, and the power available not being great enough.

Should he be able to get his machine around a full half turn, which he might be able to do in three seconds, the machine, even though assisted by all the power of its engine, and the effect of the wind in the direction it had turned, could not in that limited time have gotten up sufficient headway against its own inertia so as to be moving as fast as the wind itself, and the wind would actually be blowing from behind and aiding gravity in forcing the machine downward. It seems hardly probable that under such conditions it would be possible for the operator to again right the machine, even though it were falling head first, especially if he was not aware of the actual cause of the trouble.

As a matter of fact, a machine under such conditions as above outlined would, in so far as the forces of gravity and inertia are concerned, have to start from a standstill and acquire a velocity of 80 miles per hour relative to the earth before again obtaining its normal supporting power of 40 miles per hour relative to the air in which it would be flying.

A further complication would be the fact that once commencing a turn under the conditions above stated, the machine would have a tendency to turn practically on its own center, and having thus acquired an initial rotary motion with little forward motion in the same plane, it would be much harder to check or reverse the turn. Any effort which might be made by the operator would probably be such as would result in just the reverse to that intended, as the conditions of support would for the time be reversed.

The support of a flying machine in the air depends upon a nice adjustment of speed relative to the air, its surface and power, as opposed to the action of gravity. The power may be so applied when flying as to store up within the machine dynamic force which would be the product of its speed relative to the earth and its weight, or simply to overcome the static force caused by gravity, if the machine were flying against a wind blowing at the same speed required for sustention. In fact, if the machine were flying against a wind blowing relative to the earth at greater speed than the speed of the machine through the air, it would then have stored up within itself dynamic force acting in the opposite direction to which the machine would be actually moving through the air.

It seems evident that a flying machine may be turned very quickly and may, on account of the small frictional hold it has upon the air, and due to momentum, or centrifugal force, skid a considerable distance in making a turn, unless the resistance available by banking the machine is adjusted very nicely to the relative forces brought about by the speed of the machine.

It is the writer's belief that such quick turns, if made in a wind, are extremely dangerous and are responsible for at least some of the fatal accidents which have occurred.

Professor Langley, the writer believes, was the first to compare the flight of an aeroplane to a skater passing rapidly over thin ice, which would sustain him safely so long as he maintained sufficient speed to distribute his weight over a sufficient area. Let us go a little further with this illustration; we know that the skater might turn his body around while passing swiftly over such thin ice, and still continue on in safety, but should he check his speed and endeavor to reverse the direction of motion, he would surely break through. So with a flying machine; if turned too quickly, its momentum would tend to carry it along in the direction in which it had been flying until it reached a critical position without sufficient support from speed in the direction it had been turned.

Safety in either case could be assured only by making a long turn that would meet the requirements of time, weight, and surface; and, while the skater might turn on his own center, skating either face forward or backward, without affecting his safety so long as he maintained his speed, the flying machine must of necessity at all times present its front directly toward its direction of motion, and at the same time maintain its proper angle of incidence and forward speed relative to the air to prevent its falling.

This essential condition that the machine must be moving at its full speed relative to the air and in the direction it has turned irrespective of the speed of the wind or the relative speed of the machine to the earth, and the fact that such changes in direction when flying in a wind may bring about or require rapid changes in the actual velocity of the machine itself, so that at all times it may have a normal speed relative to the wind, is, the writer believes, responsible for conditions which we have not had to consider in other methods of transportation prior to the advent of the flying machine.

It is believed that a greater power is required to get a machine off of the ground than that necessary to maintain it in the air in horizontal flight.

If making a flight in still air, the machine might start in any direction on level ground. The power required would be that which would be necessary to overcome the head resistance of the air, the frictional resistance of the air, the action of gravity, and the inertia of the weight of the machine in bringing it up to the speed necessary for sustention, in a given time. After attaining this speed, that portion of the power required for overcoming inertia would remain in the machine as kinetic energy, and when flying in still air would remain constant irrespective of the direction in which the machine might be flying.

If a machine were started from a stationary position on the ground against a head wind blowing at a speed equal to that necessary for the support of the machine, no power would be required to overcome the inertia of the machine in a horizontal plane; it would maintain its relative position to the earth; and if it were possible for the wind to instantly stop blowing, the machine would fall durng the time necessary to accelerate the machine up to a speed necessary for support.

If a machine were started from a stationary position on the ground, moving in the same direction with a wind blowing at a speed equal to that necessary for the support of the machine, it may be assumed that, if sufficient time is allowed, the force of the wind will accelerate the speed of the machine up to the speed of the wind, but from this time until the machine obtains a speed necessary for support greater than the speed of the wind, the same elements of resistance will have to be overcome as in starting from the ground in still air, including the power and time necessary to overcome the inertia of the machine.

The above statements, the writer believes, demonstrate the fact that in flying in a wind and making a turn, the necessity for quick changes in the actual velocity of the machine, required to accommodate the speed of the machine to the speed of the wind when the direction of the machine is changed, may be such as to cause the machine to fall for want of sufficient surplus power to meet such variable conditions, or on account of not allowing sufficient time for the small amount of power available to meet the requirements of changes in the actual velocity of the machine.

In flying in a wind it would seem as if there must always be a variable resistance or momentum to be considered when making a turn; that this variable will be proportionate to the speed of the wind, and must be provided for, when turning, by the allowance of ample time for increase or decrease of the actual speed of the machine so that it may at all times maintain its normal speed relative to the air. Also that, in making such adjustments of time and speed, the weight of the machine, the normal speed, the amount of surface, and the surplus power available will all have to receive due consideration—in the hands of an expert operator who has become thoroughly familiar with these conditions and their relative values—if safety in flight is to be attained.

A flying machine cannot, without risk of falling, be turned in its course through the air without allowing the necessary time relative to the power and weight to overcome its inertia and maintain its speed in the direction it has turned.

For the sake of argument, consider what would actually happen to a flying machine weighing 1,000 lb. moving through the air at the rate of 60 ft. per second, or 40 miles per hour, and making a complete turn in the air in six seconds, while the wind was blowing at a speed of 40 miles per hour, the turn to commence when the machine was flying against the wind and practically standing still relative to the earth. In making such a turn in still air, the machine would traverse a true circle about 360 ft. in circumference, both in the air and relative to the earth, commencing and completing the turn with the normal speed necessary for sustention, 60 ft. per second in the air and relative to the earth's surface at all points of the turn.

In making a turn in the air with the wind blowing 40 miles per hour, the machine would, if it were not for the effect of inertia, traverse a true circle relative to the air just as when turning in still air; but relative to the earth, it would move in the direction in which the wind was blowing 60 ft. per second. But on account of inertia, in making such a complete turn the weight of the machine, 1,000 lb., would have to be accelerated from a standing position to a speed of 120 ft. per second in the first three seconds of the turn, and retarded from this speed to a full stop in the last three seconds of the turn.

As a matter of fact, a flying machine may be turned around in about six seconds and with comparative safety in still air, but to make such a turn and at the same time increase the speed of 1,000 lb. weight to 120 ft. per second, and again retard it the same amount in six seconds, is beyond the power available for acceleration or the strength of the machine to act in retardation, especially if we consider the fact that the power available for acceleration would be very small, practically all of the power being actually necessary to support the machine in the air. The amount of power available over and above that required for sustention may be approximated by the ability of the machine to rise. For instance, if a machine weighing 1,000 lb. were capable of rising 100 ft. per minute, this would indicate that it had 3 h. p. or 100,000 foot pounds per minute of surplus power above that required to maintain speed of sustentoin. Three seconds is one-twentieth of a minute, so that we would have 5,000 foot pounds available for three seconds to increase the velocity of 1,000 lb. weight to 120 ft. per second. It would take about 140,000 foot pounds to do this in three seconds, or about a minute and a half to accelerate 1,000 lb. weight with the energy available, 5,000 foot pounds.

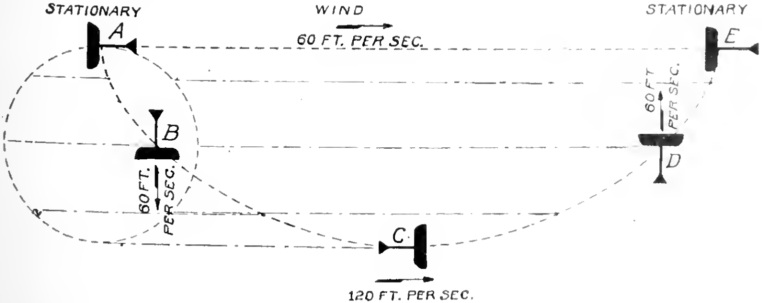
These figures are merely approximations made to illustrate the conditions involved.

The wind would assist in acceleration on the first half of the turn, and the resistance of the air to forward motion would help decrease the time necessary on the last half of the turn. This would materially decrease the time required for the complete turn. The arbitrary conditions mentioned herein are used for illustration only. The actual time in which a safe turn may be made in the air may be closely estimated, if we have the weight of the machine, know how much surplus power it has, know the speed of the machine relative to the air, and the speed of the wind.

The product of these factors would be varied somewhat by the area of the surface of the machine, the form of the machine, and the ability of the operator to control it to the best advantage.

A diagram may be made, graphically showing any combination of the conditions governing the turning of a flying machine in the air.

To illustrate the conditions above mentioned, the following method is suggested:



Let *A, B, C, D* and *E* represent five different locations of a machine relative to the earth when flying 40 miles per hour against a wind blowing 40 miles per hour, and making a complete turn, the dotted line representing the course of the machine relative to the earth in making the turn, and *A, B, C, D* and *E* relative positions of the machine during the turn. The machine would be standing still at *A;* it would have turned a quarter of a turn and increased its speed to 60 ft. per second at *B;* half a turn and a total acceleration of 120 ft. per second at *C;* three-fourths of a turn and retarded to 60 ft. per second at *D,* and a full turn to a stationary position relative to the earth at *E.* It would therefore appear that such a turn could not be made safely in much less than a minute and a half under conditions previously stated.

If the machine were flying in still air, it would have completed a true circle both relative to the air and earth, and location *E* would coincide with location *A* on one side of the circle. This it might do safely in a few seconds of time.

Such a diagram might be made to show time, weight, distance, speeds, etc., and their relation to each other for any specific construction of machine, and in this way establish limiting conditions which would be a guide to the aviator in governing the movements of the machine, so as to be able at all times to keep it under safe control.

It is believed that some of the accidents referred to have been due to a combination of the above named causes, and the failure of the aviator to appreciate their varying influence as compared to his speed through the air and his relative speed over the earth due to the speed of the wind. It is only when quite near the earth that the relative speed of the machine may be judged of; when higher up, the aviator's attention is given to necessary adjustments to meet the changing conditions in the air.

On approaching the ground, he has no way of determining the direction or speed of the wind except by noting some object such as smoke or a flag, or by first flying in a circle near the earth and noting the amount and direction of the side drift of the machine. And it must be admitted that to do this even approximately must require a highly cultivated sense of speed and direction. Any speed indicator placed upon a machine can only show the speed through the air. Nevertheless, such an instrument is of the highest importance as a guide, to limit speed in gliding and to maintain necessary speed for sustention. It is quite possible that accidents have occurred on account of lack of knowledge of these relative speeds.

This paper has been presented with a belief that it will give rise to a discussion of the subject which may lead to further investigation, and perhaps develop a greater interest in the possibilities of the flying machine from the standpoint of the engineer.

The writer has long been interested in this subject and determined about a year ago to commence the construction of an experimental machine, with a view to in some measure safeguard the operator by devising a construction which will, he believes, have a large margin of natural inherent stability in the air.

Before commencing this construction, he had become thoroughly convinced that a machine could be built to meet the following requirements, which it is believed are fundamentally essential to safety in flight:

> 1st. That the machine should be designed so that without manual control, it will automatically assume and maintain a straight horizontal line of flight when operated under power, and a proper minimum gliding angle forward when the power is shut off.
>
> 2nd. It must at all times automatically maintain its transverse stability when in flight, or when gliding without attention of the operator, or the intervention of intermediatory mechanically operated devices.
>
> 3rd. It must be capable of being positively controlled by the operator by a single simple controlling member to accomplish all of the operations of steering in any direction or of changing the lateral inclination of the machine to meet unusual requirements which may be met with in flying or brought about by the operator in steering.
>
> 4th. Such a machine should be built so as to have the same factor of safety relative to the strains involved in actual flying conditions as would be allowed for any other refined construction, upon which it is intended to carry the risk of human life.

These requirements have been stated simply to indicate the line of thought which has led up to a belief that some combination of the conditions as outlined in this paper have been responsible for a number of the fatal accidents with flying machines.

Acrobatic stunts and thrillers involving quick turns have been accomplished with apparent safety by competent aviators in still air. To attempt such demonstrations in a strong wind, whether it be blowing steadily or not, before we know definitely about all the various factors involved in safety in flight, seems to be an endeavor to beat some of the well known laws of the resistance of weight to a change of motion, and likely to prove suicidal for the experimenter.

Discussion.

President Chamberlain: The author of the paper before us this evening is one of our own members who has made quite a study of flying machines. His subject is a very timely one,—probably one of the most interesting and live topics that have come before the engineering profession, and I might say the mechanics of the country, for some time. At present I suppose there are more people working on the heavier-than-air aeroplanes than on any one line of machine. I can remember, very early in my life as an engineer, talking with a bright mechanic in regard to aeroplanes,—or flying machines as we called them then,—who said, "That is one thing I never expect to see, a machine that will fly." This was probably some eighteen or nineteen years ago, and most of us today have seen to some extent the development of the heavier-than-air machines and we have seen them fly.

Mr. Stephens: Since I came here this evening I have been asked as to the probable future of the flying machine. I will answer that question by asking another. Do you know that the flying machine, crude as it is, is capable of carrying a heavier load in proportion to its own weight a given distance, at a greater speed, with less power and fuel consumption, than the perfected automobile?

M. B. Wells, M. W. S. E.: It seems to me that some conclusions arrived at in this paper are due to a misapprehension in regard to the terms absolute and relative velocity. When we speak of absolute velocity we refer to some object that we assume is fixed. In this case the earth is the fixed object and we have the absolute velocity always referred to as that with reference to the earth. The relative velocity, since we have two objects that are moving, is the velocity of the flying machine with reference to the wind. When we want to get the change in velocity between any known velocities at two different times, we take the difference between the two known velocities, and the result is the change in the velocity in the time. This applies whether the velocities at the beginning and the end of the time considered are in opposite directions or in the same direction.

Consider, first, that the flying machine is turning in still air at the speed assumed here,—40 miles per hour,—and consider that the absolute velocity to the right, we will say, is plus velocity, and that the absolute velocity to the left is minus. In this case, if we take plus 40 miles per hour and subtract from it minus 40 miles per hour, we will have a change in absolute velocity of 80 miles per hour that this flying machine changes in the three seconds of its half turn. When the air is still, the absolute and relative velocities are equal. The only difference that exists when the machine is flying in the 40-mile wind at a relative speed of 40 miles per hour is that the machine starts the turn, when headed against the wind, with an absolute velocity of zero, and ends the half turn with an absolute velocity of 80 miles per hour, the change in absolute velocity being the same in each case. Its velocity relative to the wind, since the wind is moving at 40 miles per hour, is 40 miles per hour at the beginning of the flight in a forward direction—that is, against the wind. Its velocity at the end of the half turn, in the direction of the wind, with reference to the wind, is 40 miles per hour; and the change of velocity with reference to the wind is 80 miles per hour as before. So that, assuming the velocity of the wind to be uniform, the conditions are exactly the same for the turning of a machine in a high wind as they are in still air.

After a machine leaves the earth its absolute velocity is not a factor in the evolutions it may perform. The only interest that the aviator need have in his absolute velocity is with reference to the place of landing. It may be argued that the power of the engine is insufficient to overcome the inertia of the machine, and change its velocity 80 miles per hour in three seconds. That may be true, but the inertia is made up by the machine dropping—falling—to a certain extent. Anyone who has seen these quick turns realizes that the machine falls very appreciably through the turn, during practically all of the turn. The power is never sufficient to raise the machine while it is turning, and it always falls some. In doing that it makes up the power that the engine lacks.

A closed railway car moving on a straight track with a uniform velocity would have its contained air in the same condition with reference to the earth as the air in a wind. The action of a fly in such a car is exactly the same as if the car were at rest. The wind is moving in the car with reference to the earth but is stationary with reference to the car.

Referring to the thin ice argument: Suppose the car has ice on its floor. A skater can perform just the same if the car is moving with a uniform velocity and is stable as he can on the ice on a motionless pond. In regard to the quick turn on the ice of a pond, a man's skates continue to sustain him after he has whirled and is running backward. The flying machine cannot skate backward on the air, and the comparison does not apply.

Now I do not mean to say absolutely that a man in a flying machine can turn as well in a wind as he can in still air, because the irregularity and turbulence of the air are greater. Possibly the condition would approach the same as still air if he gets high enough to get out of the way of the turbulence that is occasioned by objects on the earth disturbing the air currents. In general, the reasoning in this paper is erroneous.

President Chamberlain: I think that this discussion has started along the lines that the author anticipated when he said in his second paragraph, "The writer is aware of the fact that some of the statements and deductions made herein, when considered from certain viewpoints, are not in accord with the laws of dynamics as ordinarily accepted," and this is probably bringing out the very line of discussion that he anticipated when he wrote that paragraph.

Grover F. Sexton: I wonder if it will not simplify the matter to recall that in practice and in theory as soon as the machine gets off the ground, no matter at what speed the wind is traveling, the machine itself is traveling in practically still air, whether it flies one mile or one-hundred miles an hour.

Also, I wonder if a little fault in the paper does not lie in the confusion of gravity with inertia. For instance, take the reference to a man in a car—a man walking in the opposite direction to that in which the car is going, and at the same speed. The paper argues that if the car suddenly stops the man will not suffer any inconvenience in maintaining his relation with the earth; he will stop dead-still. I will quote from the paper:

> "Now, for the sake of the illustration, consider what would happen if the 40-mile wind could be suddenly stopped. The machine, having no initial velocity or momentum, could get no support from the air until it could acquire a sufficiently high relative velocity."

I wonder if the writer has not confused the question of gravity with the question of inertia? If the machine is moving at all it has inertia, and the machine is moving in relation to the medium in which it is floating,—the air,—so that the machine has its momentum just the same. The manner of computing the inertia of the machine is just the same if we consider it moving in a wind as if we consider it moving in the still air. The formula is the same; it considers a mean from which that is figured, and in this connection, instead of it being the earth, as soon as it gets off the ground then the point or mean is air, so that it has its inertia at that point. Instead of the machine dropping directly to the earth in this case, since it has momentum, the machine would retain its momentum or inertia in relation to the air as it had it; but the effect as seen from the ground would be as if the machine would suddenly jump ahead.

There was another point I noted. Of course, there has been a little mistake made in this theory of going above the ground. The fact is, the farther above the ground one goes the more severe, always, is the wind,—it is full of holes, as they say.

I present these two points simply as matters for discussion, thinking that possibly here the inertia has been considered from the gravity standpoint, and also that it is forgotten that as soon as the machine gets off the ground it is always flying in the still air, from the aviator's standpoint.

E. A. Rummler, M. W. S. E.: I think both of the gentlemen who preceded me in discussing the paper are in error, and this can perhaps be shown best by a consideration of the flying machine itself. I think it is wrong to try to prove a proposition in regard to a flying machine by showing analogies, because there are no analogies that are exactly the same. The nearest analogy that I can conceive of is the one which Mr. Stephens mentioned,—the skater on thin ice,—because there sustention is due to velocity. Sustention is due to velocity through the air in the one case, while in the other case sustention is due to velocity over the ice. The flying machine cannot have a backward velocity through the air and maintain sustention. The skater can reverse and glide backwards or turn in any direction, and as long as he is maintaining sufficient velocity he will be sustained. But with the flying machine, its sustention is due to its velocity through the air in a forward direction only.

President Chamberlain: Would it make any difference if the velocity of the machine was through the air or the air against the machine?

Mr. Rummler: The difference is immaterial except when turning is attempted. Inertia is the resistance of mass to change of motion. The effect of inertia is present just as much as a resistance to the starting of motion from rest, as it is to the stopping of a body which is in motion. For instance, if a flying machine suddenly reverses, when flying against a wind under the conditions mentioned by Mr. Stephens, I believe it will fall. The resistance of inertia to rotation about the center of gravity will be considerably less than the resistance of inertia to translation, and for that reason it will be a much easier matter for the machine to turn as on a pivot than it will be for it to acquire a translatory velocity from a state of rest. Furthermore, the acquirement of velocity requires time, and I believe the gentlemen referred to have overlooked the element of time in their consideration. Now if it is conceived that this machine while at rest suddenly reverses so that it instantly faces in the opposite direction, the air pressure is no longer a sustaining air pressure but it is a pressure that is tending to force the machine down; it is tending to assist gravity in forcing it down.

President Chamberlain: If the machine is operating in the opposite direction, the motion of the machine with reference to the air is precisely the same as it was before.

Mr. Rummler: But in order to acquire sufficient velocity of movement in the opposite direction instantaneously, requires infinite power.

President Chamberlain: You are referring to movement in reference to the earth, not in reference to the air?

Mr. Rummler: Not in reference to the air; in reference to the earth. It is incorrect to speak of inertia of a body or momentum of a body with respect to the air. Momentum and inertia can be spoken of only in reference to the earth; that is, to the position of the body in space. Therefore, when the machine is stationary and pivots on its center, the air is already moving, and has already acquired its momentum and its velocity. But this machine is at a standstill in space and, to maintain sustention after turning 180°, it must acquire a velocity not only equal to but double that of the air. We have assumed that a velocity of 40 miles per hour is necessary to acquire sustention. Therefore the machine must acquire, after turning, a velocity of 80 miles per hour in order to sustain itself in a wind of 40 miles per hour. It cannot do that instantaneously. As Prof. Wells says, it will compensate for that difference by falling. This is due to the fact that it has not been able to acquire the speed necessary to sustain itself in the 40-mile wind. Therefore it falls, and by falling it glides forward and acquires that additional support, if it is kept in control during the fall. But in falling, in the turns made as rapidly as Mr. Stephens has stated in his example, the machine, when no longer going at 40 miles per hour with respect to the wind, has not sufficient power to sustain itself. Therefore it has no upward pressure or a very much reduced upward pressure upon its aero planes. The stabilizing devices, such as ailerons or warping wings, must have that upward pressure against them in order to have the effect which they are intended to have, and therefore the machine is helpless, and unless it is so arranged that it will automatically assume a horizontal position when it is falling, it is impossible to tell what position it will assume when that pressure ceases.

W. A. Blonck: My experience in European air navigation has been along the line of lighter-than-air machines, or dirigible balloons, in which I made several long trips last summer during my sojourn in Germany; however, I paid a good deal of attention also to the heavier-than-air machines, or aeroplanes.

As I understand it, the heavier-than-air machines have at the present time three inherent deficiencies, which hamper the development for general use:

First, the lack of variation in speed. For a given weight of machine and operator, a larger carrying or plane surface is required for slower speeds and a smaller plane surface for higher speeds. The solution of this problem appears to lie in the use of folding metal wings, which should be automatically spread for lower speeds and folded for higher speeds.

Second, the lack of automatic stability. The successful operation of each heavier-than-air machine represents at present about 90% human ability and 10% machine. At Belmont Park, New York, it was proven that the make and style of the machine had little or no bearing on the performance, but that the operator's skill had everything to do with it. In France, I understand, they have recently tried to get a gyroscopic device in connection with the motor, in which case the engine works in the opposite direction to the propeller; how much automatic stability this device insures was not stated.

Third, the lack of engine reliability. To have a larger assurance of safe operation, a multiplicity of engines should be installed on the heavier-than-air machine; however, due to the lack of stability, no repairs or interchange of parts can be made on these engines while the machine is in the air.

I call attention to the fact that the press in this country has often reported great failure of lighter-than-air machines abroad, but a closer local investigation showed that the difficulties encountered by the dirigibles of Zeppelin, Gross, and Parseval have nearly all been due to engine trouble in the critical moment, when striking a heavy wind or gale. The newer and latest dirigibles of larger capacity are all equipped with four engines up to 600 H. P. total capacity.

Taken from a practical standpoint at the present time, the aeroplane has proved to be a great success for scouting in military service, but as far as the act of commercially carrying passengers is concerned, it cannot do anything along these lines unless the aforesaid deficiencies are fully or partly overcome, because no insurance company under the present circumstances will ever write a policy, either for operator or passenger, on these machines.

In Munich, Dresden, and Berlin, Parseval airships carried last year more than a thousand people; insurance was written for all passengers, crew, and even the motor-balloons and there was not a fatal or serious accident in the entire period.

An official statement of the performance of the airship "Parseval 6" during the last months of 1910 is as follows:

Number of runs	73
Total hours in air	132
Number of passengers carried	642
Total miles traveled	3542

However, the heavier-than-air machine has still a great field in express mail service and in quick transportation of single passengers to be taken to a certain place, in cases of emergency.

As thousands of inventors scattered over the entire civilized world are working at the present time on the development of the heavier-than-air machines, I hope the author's very positive statement that a machine with perfect safety can be constructed, will be realized in the near future, as this will mean the greatest step in advance for the perfection of the heavier-than-air machines.

W. E. Symons, M. W. S. E.: I wish to disclaim ability to criticise the views of those who have devoted time and study to the subject of aerial navigation.

The paper just presented, and the discussions so far, are quite interesting, and the critics, though differing, have each presented a thought which had occurred to me, although I am not in accord with the full criticisms. There are one or two points on which I am not yet quite clear.

A paragraph in the paper reads as follows:

> "Imagine a machine flying at the rate of 40 miles per hour, which in round numbers is 60 ft. per second, directly against a wind blowing at the same speed. While such a machine would maintain itself in the air just as surely and safely as if it were flying on a calm day and covering a distance of 40 miles an hour as measured on the earth's surface, it would in fact actually be standing still, in so far as its relative

> position to the earth is concerned, and the entire output of its engine would be expended in supporting it against the action of gravity and preventing it from drifting backward in the wind."

If I understand and correctly interpret the author's position as defined in this paragraph as to moving against an opposing wind of the same velocity as the machine, it would result in the machine coming to a state of rest as to horizontal movement, and the air current acting on the machine would be only 60 ft. per second.

I am inclined to disagree with the author on this point, as it appears to me that a machine flying 40 miles per hour in a dead calm would be forced against the atmosphere at a speed of 60 ft. per second, and at which speed each square foot of exposed area of the machine would meet with a resistance or pressure of 7.87 lb. Now if this machine encounters an opposing wind of the same speed, 40 miles per hour, I believe that under the conditions first named by the author the machine is still traveling 40 miles per hour as measured from the earth's surface, but that the atmospheric resistance it encounters is that of an 80-mile an hour gale or hurricane, the wind pressure being about 31 lb. per sq. ft.; under these conditions the machine would be more sensitive to its steering mechanism than when traveling 40 miles per hour in a dead calm.

If a machine only had engine capacity to attain a speed of 40 miles per hour in a dead calm, and while moving at that rate of speed should encounter an opposing wind gradually increasing in velocity up to 40 miles per hour, I am inclined to believe the machine would decrease in speed inversely to the increased speed of the wind, and with the latter at 40 miles per hour the machine would in its relation to the earth be standing still. But as the conditions named by the author are not so stated, I think the conclusions reached are in error, although the proposition may have been purposely so stated to induce discussion.

The effect of running with, or against, wind currents may be not entirely unlike operating power-driven vessels in navigable waters. Our maritime laws very wisely provide that when craft pass in a stream, or where there is a current, that the craft descending or running with the current has the right of way; the movement and control of the craft moving against the current can be more easily managed. This is predicated upon the assumption that, if there be an 8 mile current, the vessel descending or running with the current would need to run at a greater speed to secure the same benefit from its rudder or steering mechanism, as the vessel headed against the current would have when standing still in its relation to the earth, but while so standing would enjoy the same benefit from its steering mechanism as though moving 8 miles per hour through an eddy or still water. This comparison refers only to the course or direction of a vessel in the water, while in aerial navigation, both *gravity* and *direction* must be overcome by speed or its equivalent wind currents.

The author makes reference to the "so-called Swiss cheese sky" or "holes in the air", the varying air currents being charged with many difficulties in aerial navigation, which, in the opinion of the author, may in some instances be due to other causes.

The behavior of birds—particularly the larger variety, such as eagles, buzzards, owls, hawks, and sea gulls—in the different air currents offers some suggestions to those giving this feature thought or study.

Take, for instance, birds of prey,—the eagle or the hawk. They may be observed soaring placidly at considerable height when suddenly a dart downward is made to the point of the object of prey. This movement is sometimes so perfectly graceful and accurate as to challenge the admiration of the highest authority on Nature's laws, while at other times the bird comes in contact with air currents that are difficult to navigate and not infrequently results in missing the objective point. It is also quite noticeable that fowls of the air, especially the varieties above mentioned, usually seek shelter during heavy wind storms, where they remain perched on a tree, rock, or even the ground, until by instinct they understand it is safe to again enter the elements to which Nature assigned them.

Another illustration of sharply defined air currents may be noted in the case of a captive balloon, with a cord or line that holds it captive bearing small flags or streamers spaced about 20 ft. apart. The balloon may be in perfectly still air, its flag or ribbon decorations hanging, apparently almost lifeless, while the decorations on the cord or line to earth may, at a given moment, be, at the different levels, under the control of air currents from entirely different directions and at varying speeds. It is therefore my thought that in the author's closing sentence of the seventh paragraph of his paper, the adverse effect of varying air currents is slightly underestimated.

Such comments or criticisms as I have offered, it should be understood, are more for the purpose of securing additional information from the author in his closure, than in the nature of a contribution to the subject, and if I have misinterpreted any of the matter referred to, I hope the author will point out the error in his final review of the discussion.

Alexander von Babo, M. W. S. E.: In this very interesting paper I find a statement to the effect that a machine, flying at the rate of 40 miles an hour, directly against a wind blowing at the same speed, would maintain itself in the air just as surely and safely as if it were flying on a calm day and covering a distance of 40 miles an hour, as measured on the earth's surface.

This conception, though in conformity with some text-books on aeronautics,—in which it is plainly stated that it is the same or equivalent in aeronautical problems, whether a surface moves with a certain velocity through surrounding stationary air, or whether the surface is stationary and the surrounding air moves against it with an equal velocity but of opposite direction,—to my mind is absolutely wrong, and as it may have been indirectly the cause of many accidents, I shall try to explain why I think it is wrong.

A successful flying machine must have two essential qualities. *First,* it must have the ability to carry itself through and in the air, and, *second,* it must have a certain amount of stability during this carrying process.

The first quality depends, as we all know, mainly on the maintenance of a sufficient relative velocity between its carrying surfaces and the surrounding air. If these surfaces are well proportioned, the carrying capacity of a flying machine will increase with its velocity, relative to the air, and it is in this respect practically equivalent at least for plane and slightly curved surfaces, whether the machine moves in stationary air or in moving air, as long as its relative velocity to the surrounding air is the same in both cases.

The second quality, the stability or the ability of the machine to preserve its equilibrium under all circumstances, is a problem yet to be solved; until this is satisfactorily done, we shall have to make use, as well as we can, of all we know from natural laws, and from what we have learned by experience in connection with other unstable vehicles.

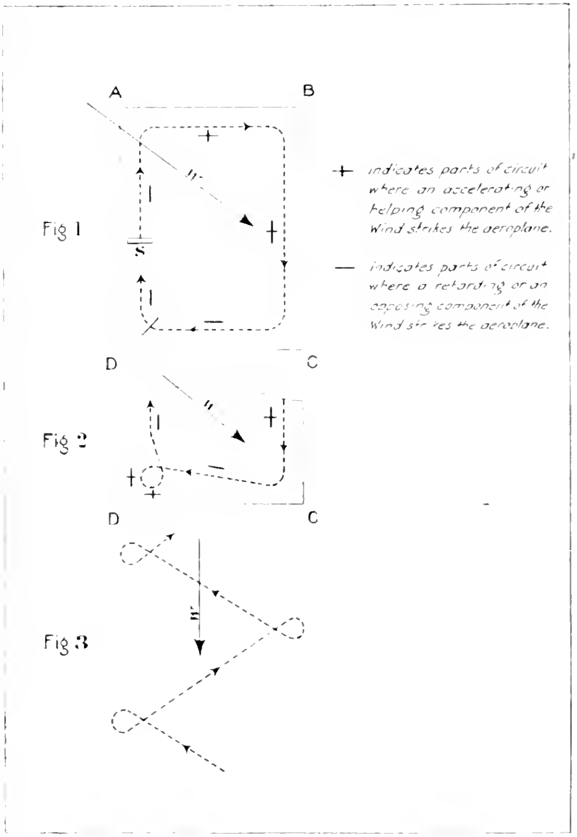
We know from physics that the faster a body moves, the more power is required to turn it perceptibly out of its course; in other words, the center of gravity of a rapidly-traveling body tends to move in a straight line; the greater its velocity the smaller, in comparison with its momentum, are the disturbing or side forces. By momentum of a body I understand is meant the product of the mass of the body multiplied by its velocity. As practical demonstrations of this fundamental law, I will mention the behavior of a bicycle which—as everybody knows— becomes more stable and less affected by side forces (for instance, a wind striking it from the side) the faster it moves; or the behavior of a canoe which, if swiftly moving in stationary water or with the current in moving water, proves to be a good deal more stable than if it is paddled against a current without making much or any headway. If the current is very rapid, it takes some practice to keep it in line (parallel with the direction of its intended course) and prevent it from being suddenly turned from its course, not to speak of the danger of being upset.

Returning to the flying machine, let us consider that its main center of gravity (which, in general, is located in or near its motor) is the resultant center of gravity of partial centers of gravity of the motor, of the right and left half of the aeroplane proper, of the steering apparatus, and of the man or men riding on the machine. Assume, also, that such a machine has at a certain time a great velocity relative to the earth. We now easily understand that all partial centers of gravity of the several constituent parts of the apparatus, each for itself, endeavor to move in straight and parallel lines or paths. Also, on account of the velocity of the machine and consequently its momentum, the side force required to throw it out of its path or to tip it either in a transverse or longitudinal direction will be the larger, the greater the velocity of the machine relative to the earth and consequently the greater its momentum. In other words, a flying machine will be more stable and safer, the faster it moves relative to the earth, similarly to a swiftly-moving bicycle.

If, on the other hand, a flying machine moves at the rate of 40 miles an hour relative to the surrounding air, and directly against a wind of the same velocity, the machine is at a standstill relative to the earth, and the momentum of its several parts will be zero, whereby also its transverse and longitudinal stability will be greatly diminished. Its stability against tipping and rolling will depend, then, practically on the motion of the opposing wind. The amount of assistance coming from the resisting force caused by the inertia of the actually stationary aeroplane in opposition to any starting straight or rotary motion, and also coming from the gyroscopic quality and action of the swiftly-rotating air-propellers and of other rotating machinery parts, might be considered as insignificant or at least not sufficient for the preservation of equilibrium. Therefore, as long as said motion of the wind is quite uniform, the equilibrium may be preserved for a time, but if the wind blows in streaks or gusts, it will become an extremely difficult and dangerous task for any aviator to keep the machine balanced. In such a case the stability of the apparatus against tipping in any direction may be considered about the same as if the entire machine were hung up by a single rope at the main center of gravity, or if the latter were resting on a pointed support. Under such a condition only a small eccentric force would suffice to tip the machine, and, in doing so, would change the angle of incidence of the air current, and consequently would influence also the carrying quality of the machine. If such an eccentric force exceeds a certain limit, a catastrophe might be the end of the flight.

If my reasoning is correct, it may perhaps serve to give a plausible explanation of certain occurrences in connection with aeronautic performances.

I think it was last fall that I read about flights being made over an aviatic field near New York, where a certain corner of the field was feared by the different aviators because of the difficulty and danger of making a turn or a curve. Let us assume that this aviation field had the rectangular shape *A B C D*, Fig. 1, and the prevailing wind during the aviation week had the direction *W*. If, then, an aeroplane started at *S*, and moved first to the corner *A*, a component of the wind acted against it, but reaching *A* where it had to turn towards *B*, the opposing or retarding wind component changed at once into a helping or accelerating component, when the turn consequently could be accomplished with relative ease. The next turn at *B*—where the aeroplane arrived accelerated by a wind component and turned in the direction towards *C*, where it met again with an accelerating component of the wind—was still easier to make than the one at *A*. Reaching *C*, the machine was again accelerated by the wind, and the third turn could be made about as easily as the turn at *A*. Flying from *C* to *D*, however, the wind component had a retarding influence, so that the machine not only arrived at *D* with a diminished speed, but in making the turn at *D* it had also to fly squarely against the wind, and if the wind during such a performance had any strength, this was certainly the most critical place for any aeroplane making a circuit, because its speed relative to the earth was here reduced to a minimum. Under such or similar conditions it would be perhaps preferable,


A
B
Fig 1
S
+
+
−
W
+ indicates parts of circuit where an accelerating or helping component of the Wind strikes the aeroplane.
— indicates parts of circuit where a retarding or an opposing component of the Wind strikes the aeroplane.
D
C
Fig 2
W
+
−
+
+
D
C
Fig 3
W

instead of making a 90° turn directly against the wind, to make a turn of 270° more or less in the direction with the wind, avoiding thereby the facing of the wind squarely. (Fig. 2.) The same kind of curves could be applied by an aviator who, instead of flying over land directly against an opposing strong and gusty wind, tries to reach his destination by tacking (Fig. 3). Of course, he would lose at each turn a little additional height or potential energy, but he would never come to a dangerous standstill relative to the earth.

In conclusion, I would repeat with emphasis, that, to my mind at least, *it is of the utmost importance for the safety of an aeronaut, to keep his aeroplane always at a good rate of speed relative to the earth, and in doing so to preserve and maintain a sufficient momentum for the sake of stability, and to avoid facing directly a wind of a velocity which nearly equals the speed he can attain with his aeroplane in calm air.* If this rule were strictly adhered to, I am convinced we should hear less of so-called "Swiss cheese" skies or of "holes in the air", and also less of deplorable accidents.

President Chamberlain: I do not mean to intimate that I am competent to discuss the paper, but there is one point which perhaps has not been very clearly brought out; that is, that we are dealing in this paper with absolutely theoretical conditions—conditions which do not exist. My own conception of the matter is that an aeroplane, under the conditions stated in the paper, is acted upon simply by two forces,—the force of gravitation, supposing the aeroplane to remain the same distance from the earth all the time, and the propelling force, supposing the engines to be acting with a constant propelling force. I must confess that I fail to see any difference in the conditions whether the aeroplane is moving with or against the wind (that is, considering the velocity of the wind with reference to the earth), because it seems to me perfectly conceivable to consider the machine in the air in a theoretically uniform moving air, divorcing it from the earth, acted upon by two forces. I fail to see that the conditions are any different whether the air is moving in reference to the earth or whether it is stationary with reference to the earth.

Mr. Rummler: I think that was the reason the paper was written: aviators have not appreciated the effect of inertia, and naturally when we commence to study the laws of flying machines we conceive that the machine is in the air, that it moves in the air, and is carried with the air wherever the air goes. But air is matter. It has a certain momentum and it also has inertia. The flying machine also has momentum and inertia, but it is much heavier. To change the speed of the flying machine requires power, and it requires time, and it cannot be instantly changed without infinite power.

I am convinced of the correctness of Mr. Stephens' theory, as outlined in this paper, and believe that he has brought out points of great importance to the future of the art of flying. I hope his ideas in this regard will be given the widest publicity. Such publicity will at least result in further experiments and lead aviators to exercise greater caution in turning in a wind, and also, I hope, lead promoters of flying exhibitions to be more cautious in offering prizes for the accomplishment of feats involving sharp turns which are extremely dangerous, if not impossible, in a high wind.

During this discussion, inertia has doubtless been confused by some with gravity, perhaps because, for the sake of having a datum of reference, Mr. Stephens referred to the position of the machine with reference to the earth. The inertia of a mass of matter is absolutely independent of its position with respect to any other mass of matter. It applies only to the state of a mass of matter as regards its condition of rest or motion in space; that is, it is the resistance of *mass* to change of motion considered in the absolute sense. Inertia should not be confused with momentum. It means more than momentum. Momentum is a manifestation of inertia with respect to a body which is in motion.

It would be well to consider in this connection Newton's first law of motion, which is as follows:

> "1. Every body persists in its state of rest or of uniform motion along a straight line except in so far as it is compelled by impressed (external) forces to change that state."

It has occurred to me that the effect of inertia upon the movements of a flying machine will be understood if we first consider the following simple example: If a brick is thrown vertically into the air in a 40-mile wind, the air will, on account of its impact with the brick, cause the brick to be deflected out of a straight vertical path. Although the air is moving at the rate of 60 ft. per second, I think no engineer will believe that, if the brick is thrown to such height as to remain in the air two seconds, it will be carried horizontally 120 ft. while it is in the air. A flying machine, like the brick, has mass which is great as compared with that of the air impinging upon it, and we must look upon it just as we do upon the brick with reference to its being carried along by the impact of the air.

If, at the same time that the brick is thrown up in the 40-mile wind, a sponge of the same size and form is also thrown up with sufficient velocity to keep it off the earth two seconds, the sponge will also fall short of 120 ft. of horizontal movement, but it will be carried by the wind a much greater distance than will the brick. Both the brick and the sponge have the same area exposed to the wind, and the impelling force of the air impinging against them is the same, but on account of their difference in mass, the inertia of the brick is greater than that of the sponge, and consequently the impelling force of the air meets greater resistance in the brick than it does in the sponge.

To carry the analogy to the flying machine further, we must consider the horizontal velocities of the brick and the sponge, because it is the horizontal velocity of the flying machine with reference to the surrounding air that produces the upward thrust upon which the machine depends for sustention. Both the brick and the sponge move horizontally with accelerated velocities from a condition of rest at the starting point to their respective instantaneous horizontal velocities at the end of the two seconds during which they are in the air. The acceleration and the resulting velocity, due to the impact of the air, are much less in the case of the brick than they are in the case of the sponge, and if, for the sake of the analogy, we conceive that both the brick and the sponge are provided with propelling apparatus and aeroplane surfaces so that they would be sustained by the air on acquiring a relative velocity of 40 miles per hour, it will be seen that the brick would have to have much greater power to avoid a fall than would the sponge. Or, if the propelling power with which the brick is equipped were equal to the propelling power with which the sponge is equipped, it would take a much longer time for the brick to acquire a horizontal velocity sufficient for sustention than it would for the sponge to do so. Consequently, the brick would fall farther than the sponge before it could acquire sufficient velocity for sustention. The difference in these two cases is due solely to inertia, as we have assumed that all of the other factors are the same.

As Mr. Stephens has shown in his paper, a similar condition of affairs occurs in the case of the flying machine, if the aviator attempts to turn when the machine is stationary in space, by virtue of the fact that it is flying against a wind having a velocity exactly equal to the velocity of the machine through the air.

Mr. Sexton: I think a great deal of the difficulty in not getting together is caused by those interested not agreeing on the primary definitions. For instance, an Eskimo and a native of Africa cannot agree about a stalactite, because one thinks of it as an icicle and the other as an elephant's tusk. If we could agree on our definition of inertia, we would then have no difficulty in forgetting the earth when we get off the ground.

Horace B. Wild: I have been engaged in aeronautics for the past twelve years, more or less, experimenting with balloons, dirigibles, and aeroplanes. I have made 600 trips or more in the dirigible balloon, and have built seven different craft of this type. I take some pride in saying that I hold the American record with the dirigible balloon as to duration and distance. I have made nineteen trips in the spherical balloon, seven of which were in national races. In the heavier-than-air type, or aeroplane, my longest trip was sixteen miles. Up to the present time I have made quite a number of short flights, affording me, in the experimental scope, sufficient knowledge to speak knowingly on the management of this type of air craft.

It was my privilege to be in attendance at the International

Aviation Meet at Belmont Park, New York, last fall, as Assistant Chief Timekeeper. The foreign countries had their latest and best types of flying machines at this meet, which I observed very closely. I have also discussed at length with many of the prominent aviators the principles involved in mechanical flight.

Our late and lamented aviator, Ralph Johnstone, was the one person who had the most wonderful sense of balance of any operator I have ever met. Prior to his taking up the aeroplane occupation, he was a professional trick cyclist on the vaudeville stage; he rode a motorcycle inside of a lattice globe. In one of his demonstrations inside this globe he made two circuits in a vertical plane, in one second's time; in other words, bluntly putting it, he stood on his head twice in one second. His success as an aviator was, in all probability, due to his constant drilling. His untimely death was the direct result of the collapsing of one of the wings of his Wright biplane.

I saw Johnstone and Hoxsey as they respectively left the ground, at the Belmont Park meet on one of their flights. The higher they ascended, the stronger became the velocity of the wind, which was about 65 to 70 miles per hour, carrying them backward down Long Island 40 and 55 miles, Johnstone in the lead.

Upon Johnstone's return to the field, the Wright brothers asked him why he did not descend before covering so great a distance. His reply was, "I kept going higher, trying to get out of the heavy current. I did not dare to turn in that wind. Had I done so I would surely have capsized and turned a dozen somersaults."

Latham, who is one of the world's leaders in aviation, and who, by the way, uses to the exclusion of all other machines, the beautiful "Antoinette," experienced some two or three "close calls" at the Belmont Park meet. On the windy day mentioned above, he also made an ascent. Headed towards the wind he rose almost perpendicularly, in a stationary position relative to the earth. By banking his machine at a steep angle against the wind, he turned and traveled with the wind at a terrific speed, climbing to the height of 1000 to 1500 ft. He again turned his machine into the wind and descended. The weight of his machine, added to the power or propelling thrust, gave him enough momentum to gain headway against the velocity of the wind. In other words, while climbing he lost advance. Remaining on a level keel, his power was just equal to the velocity of the wind, which kept him in a stationary position relative to the earth. When he pointed his machine down, as I have already stated, the weight of his machine, added to his power, gave him an advantage over the velocity of the wind, and he gained ground. He came in just over the top of the hangars. At this position he realized that he could not clear the tops of these buildings and descended into the field. He brought his machine to an even keel, and remained in a stationary position almost three minutes—just mastering the machine, and that was all, and being able to hold his own. Finally a lull came, just sufficient to permit him to get over the hangars, and he alighted safely in the field. When he dismounted from the machine he practically corroborated all the statements contained in Mr. Stephens' paper.

Let it be understood that I base my ideas on the subject of aviation on my own practical experience with the flying machine. But the flying machine of the future must be worked out by competent engineers in a school or association of this kind. One may take a butcher-knife and a buck-saw and crudely construct a machine that will "fly like a bird", with sufficient power applied. On the other hand, one may employ good mechanics with fine tools, and construct a machine that bears semblance to a flying machine, but which under test remains a "groundhog", and could not be raised by dynamite. There are in Chicago today some 100 aeroplanes, and only about six of this number will fly.

I have been accorded the privilege of inspecting Mr. Stephens' new machine, and it is my belief that he has in this machine a wonderful piece of work. I am not familiar with all the new prinicples involved in it, but from the information I was able to gather I judge it to be far superior to some of the machines that are flying today.

At Indianapolis, when Brookins made his first turn in 6 2/5 seconds, Wilbur Wright, with myself and some others, sat on the ground watching him. We were all sure he was falling, and he seemed to have turned over. When he came down he was severely reprimanded by Mr. Wright and cautioned to never try a short turn like that again. Some of the aviators have even tried to "loop the loop," but this kind of work is extremely hazardous. Most of those in the profession have eliminated the dangerous and spectacular elements in flying, and are devoting themselves to safe and practical aviation.

At Los Angeles Hoxsey came down 11,000 ft. in three minutes. The quick change in atmospheric pressure caused a rush of blood to his head, and under such a condition it is natural that he should have lost control of his machine resulting in the loss of his life.

Moisant also lost his life through losing control of his machine. He had placed a tank of gasoline about 7 ft. long by 18 in. in diameter, holding about 18 gallons, underneath the plane. He had learned to operate the machine under ordinary conditions, and knew how far forward to shove his control for a volplane. He had used most of the gasoline, and the portion which remained rushed from the rear to the forward end of the tank, changing the center of balance so that his machine stood on end very quickly. His safety strap gave way and he was thrown from the machine.

The law of gravity is bound to be respected. Those who disregard it, while flying, must expect to meet disaster. The law of a falling body plays its own particular part in aviation. There is a certain angle of safety away from the horizontal line of flight at which the aviator may vary his plane, and still retain control.

Glen Curtiss is one of the most successful aviators, and carries but one little scar, on his chin. I have seen Curtiss at an aviation meet, with 35,000 people on the grandstand and field the first day of the meet, when, if he would have made a flight at three or four o'clock in the afternoon, he would have secured for himself $10,000 and probably $60,000 for the promoters. On account of the condition of the wind he delayed his flight until ten minutes after six, when he thought it was safe to make the attempt. This was after most of the people had gone home, however, and "knocked" the meet, and the whole affair was a total failure financially. But when Curtiss got that little bump on his chin it served to teach him a lesson, and no one can induce him to make a flight unless he knows the wind is right.

I received one little bump in an aeroplane which I shall not soon forget, which deprived me of my eyesight for two months or over.

The Aero Club of Illinois, with headquarters in Chicago, is contemplating opening an aviation school, and is going to give instruction in the art of aviation.

W. H. Beattys, M. W. S. E.: There is one question I would like to ask. Assume the velocity of the wind to be 40 miles per hour. In turning through 180° we pass through a cycle with reference to the velocity of the wind to the aeroplane from 40 miles, to zero, to 40 miles. That is leaving out all consideration of velocity with respect to the earth. The well known feature of banking, as I take it, is simply getting the greatest sustaining power of the machine by having the pressure of the wind on the under side of the plane. Assuming that the operator of a machine makes some little flight after turning through 180° before obtaining the necessary velocity to support the aeroplane in the new direction, is it not true that as he started to turn he would bank his machine and, having completely turned, would he not have to run with the tail in the air as long as the velocity of the machine was less than the velocity of the wind? He would then pass through a critical point where the wind and the machine were of the same velocity, or the relative velocity, zero, when he would have to tip the front of the machine up. By so doing he would have the wind under the plane at all times and fall the least amount in making the turn; so that he would run part of the time with the tail up and then tip it in the other direction.

President Chamberlain: In turning an aeroplane, is it not always the case that the speed of the machine is reduced on account of the turning? I know very little about an aeroplane, but is not a part of the power of the engine—which I assume is working pretty nearly at its top speed all the time—used in the act of steering to turn? If that is the case, of course the velocity would be reduced on the turn, and this condition of falling as the turn was being made would naturally result.

Mr. Wild: I would like to answer that question. We have found that it takes 20 per cent more power to turn on a short curve than it does to fly the same machine on a "straightaway." I have driven a machine around a mile race-track and made many a turn. The operator starts from one end and begins to climb. When he gets to where he has to turn he is 150 ft. in the air. Before he has made the half turn, he will probably be within 10 ft of the ground.

An aeroplane, to fly successfully, should be equipped with an engine that will deliver sufficient thrust to sustain the machine in the air at half-throttle.

President Chamberlain: You haven't that additional power ordinarily, have you?

Mr. Wild: On the new motor there is the surplus power. If one is flying at half power on the straightaway, he can give the machine full power on the curve, but if he has only just enough power to slide the machine when he gets to the curve, he is going down.

Sydney V. James: I am very much interested in Mr. Stephens' paper, and especially in the discussion which followed it. I do not agree with him, however, in his deductions as stated, and believe that a confusion of the motions of the aeroplane relative to the air and to the ground is responsible for the difference of opinion. The case as presented by him is purely a theoretical one, namely, that the machine is performing its evolutions in a perfectly uniform and steady wind moving horizontally over the surface of the ground.

It is assumed that the aeroplane is capable of maintaining a speed of 40 miles per hour relative to the air from which it derives its support. As the machine opposes a 40-mile wind, it stands still relative to the earth, and at the end of a half turn it travels with a speed of 80 miles per hour relative to the earth. This involves the acquiring of an amount of kinetic energy, since the machine under the first condition has no kinetic energy, and under the second condition it has a considerable amount of it. This energy, the author assumes, must be obtained from the motor, and therefore argues that as it requires a large excess of power to produce the result in the short time available, and that as the present machines do not have the excess necessary, a drop must result.

An aeroplane, in turning, loses some of its lifting ability, for two reasons: *First*, because, as the surfaces incline or "bank" in order to counteract the effect of centrifugal force, the vertical component of the normal reaction of the air on the surfaces is less than the weight. *Second,* because the turning of the rudder means increased head resistance, and therefore a lowering of the speed which involves a loss of lifting force. Hence, an aeroplane, in turning, must drop under the action of gravity until the system of forces is again in balance.

Now an aeroplane in a uniform current of air partakes of the combination of its own motion relative to the air itself and that of the current of air. The gain in kinetic energy above referred to is brought about by the air itself during the first half turn, and is given up by the machine again on the other half turn, thus completing the cycle of operations. The machine has exactly the same relation to the air of the current that it would have to calm air, but its apparent motion is the result of being carried along bodily with the air during its turn. It finally completes its circle in the same part of the air current that it left in the first place.

It is of interest to note in this connection that Mr. Stephens' views coincide with those expressed by Mr. R. W. A. Brewer, in his book, "The Art of Aviation," page 209 (to be found elsewhere in this paper). I am of the opinion, however, that this is an erroneous line of argument.

It is admittedly a difficult thing to turn in a high wind, owing to irregularities and turbulence of a natural current of air, but these matters do not enter into the discussion as laid before us by Mr. Stephens.

CLOSURE.

The Author: I realized when I wrote this paper that there would probably be a number of those who heard it or read it who would decide that a person could get up in the air without the use of a flying machine.

With reference to Mr. Symons' criticism of the clause which reads: "To illustrate: imagine a machine flying at the rate of 40 miles an hour, which is, in round numbers, 60 ft. per second, directly against a wind blowing at the same speed." I think possibly he has misunderstood that clause. It seems to me that it is self-evident that if the wind were blowing at 40 miles per hour, and the machine were flying at the same speed as that of the wind, and against the wind, the machine relative to the location to the earth would be standing still. That is, it would not be moving 80 miles per hour, unless it were flying with the wind.

In reference to the arguments of Messrs. Wells and Sexton, if we are to take these statements from their standpoint, we would have to admit that a machine could be turned instantaneously, if necessary, and fly in the opposite direction and be just as safe as if it made any length of circuit. If it turned instantaneously, I contend that it must fall, because there is a weight of 1,000 lb. that must accelerate to 80 ft. per second before it can stay up and fly in the wind. These gentlemen may not agree with me in this, but as I see it they will have to admit that one could turn instantaneously. If not, how long a time are they going to allow for making the turn? If they are going to allow any time at all, it must be long enough to meet the requirements of my argument.

Something was said about the banking of the machine. I can see that in flying a machine, the aviator might wish to make a very quick turn, and it stands to reason, according to my way of thinking, that the quicker the turn he wished to make, the more banking he would have to do. But, from my point of view, I can also see how, if he banked too much, he would lose sufficient speed for sustaining power and would begin to fall.

If the generally accepted conception of the laws governing weight in motion are applied to a flying machine when in the air, neglecting the danger involved in starting and alighting in a strong wind, the machine should fly just as safely and the conditions of control should be just the same whether the machine were flying when there was no wind or when there was a hurricane, providing the wind were blowing steadily.

The machine would at all times, independent of the velocity of the wind, be moving at its normal speed relative to the air in any direction in which it might be steered.

I can imagine the sensation of flying through still air at a speed of 40 miles per hour, 60 ft. per second. I can also imagine myself, when flying at this speed, deciding to make a turn, steering the machine around in a circle, giving the machine the necessary amount of tilt to counteract the tendency to drift on account of centrifugal force, completing the full turn, and again continuing in the same direction as when commencing the turn-entering, going around and leaving the turn at the same speed relative to the air, 60 ft. per second.. If I am to base my conclusions on the generally accepted conception of the laws of dynamics, that one body moving in another body partakes of the motion of the body in which it moves, I would naturally expect the conditions of turning and flying in any direction in the air to be the same, irrespective of the speed of the wind, if blowing steadily, as I would expect the speed of the machine to always be the same relative to the air in which it would be flying. But, on the other hand, let us suppose the machine to be flying at the rate of 60 ft. per second against a steady wind blowing at the same speed. The machine might be only a few feet from the ground and actually standing still relative thereto; neglecting the effect of adding additional weight to the machine, I could get on or off the machine just the same as though it were stationary on the ground. Let us suppose that we get on to a flying machine under the above conditions; if we do not look at the earth, the sensation and conditions of operation of the machine will appear just the same as if we were flying when no wind was blowing. The machine would be moving through the air at the normal speed necessary for sustention, 60 ft. per second. Let us decide to make a complete circle in the air in six seconds. Why not? The machine is moving in the air at its normal speed, 60 ft. per second, and if steered around a circle and a proper amount of tilt is given to resist centrifugal force it should make a true circle relative to the air in which it is flying, and we should expect to fly around as smoothly as in making a turn when there was no wind.

Let us see what would actually happen if we made this turn in six seconds, getting on to the machine when it was standing still relative to the earth, through flying a few feet about the ground against a wind blowing 60 feet per second; in six seconds the air in which the machine would be flying would travel 360 ft. The machine must continue to travel through the air at the rate of 60 ft. per second to maintain itself in the air, which would mean that the machine might actually have to travel 720 ft. relative to the earth in six seconds. This also means that I must believe that I could climb onto a flying machine under the conditions stated; that I could be whisked through a distance of about 720 ft. in six seconds at an average speed of 120 ft. per second, which is at the rate of about 80 miles per hour; that the machine would at the end of the six seconds be again stationary relative to the earth, so that I might step off of it again, and that I had made this little trip with the same sensation of safety and steadiness of motion as when flying in the air when there was no wind; starting around, completing, and leaving the turn at the rate of 60 ft. per second relative to both the air and the earth.

I must admit that I cannot conceive of making this trip without experiencing a different sensation than that of flying around a circle in still air; in fact, I doubt whether I would be physically able to get off of the machine after making a turn of this nature, starting from a standstill, going possibly 720 ft. and coming to a standstill again in six seconds.

What we do want to know is this: is there any difference or greater danger in flying a machine in a strong wind than when flying when there is no wind. It is believed that there is, although to believe this is to question the commonly accepted conception of the laws governing weight and motion.

I believe that an explanation may be found in the following facts:

First, that the support of the flying machine in the air depends entirely upon a high velocity through the air in a horizontal direction and not upon displacement of the medium in which it moves, as is the case with a boat in the water. This being the case, the machine must at all times when in the air and traveling horizontally move at a fixed velocity relative thereto. Its movements must necessarily be considered from a different viewpoint than that of one body moving in another, each having approximately the same specific gravity or frictional contact capable of rapidly transmitting the movements of the one body to the other.

Second, that for a given weight, the mass or volume of the machine and that of the air vary greatly, thus calling for a proportionate difference in velocity, motion, or time for the operation or completion of the necessary re-actions which may be required in making a turn safely.

Third, that when flying, the head and frictional resistance, together with the surplus power available for retardation or acceleration, is small compared with the action of the forces of gravity and momentum or inertia. Consequently, any change in the actual velocity or direction of motion of the machine must be made slowly enough to allow time for the available power and surface of the machine to be brought into action, as opposed to the relatively varying forces of momentum or inertia, brought about by turning the machine when flying in a wind. This is to counteract any tendency of the machine to drift or skid, and thus disturb its normal speed relative to the air and by so doing jeopardize its support and cause it to fall.

This paper was written rather to illustrate how little we know about the flying machine than how much we know, and with a view, as I said in the paper, of bringing out a discussion that might lead to further knowledge than we now have. From my own standpoint, I have argued this thing to myself from both sides, and I think I can carry either side of the argument about as well as I can the other, although I am thoroughly convinced that the theory as presented in this paper is correct, especially since hearing from Mr. Wild from his practical standpoint,—and I believe we have not yet made proper rules or realized all of the dangers of flying in the wind.

ADDENDA.

Since the presentation of this paper, the following articles have been brought to the attention of the author.

THE EFFECT OF WIND ON AN AEROPLANE.*

By

MAJOR B. BADEN-POWELL.

A great deal has been said about automatic stability and contrivances to prevent the upsetting of an aeroplane by the wind. Even flying men, especially beginners, often speak of being upset by a gust, but the mishap is more usually to be attributed to faulty steering. The matter is not well understood and frequently ideas are propounded which after a little consideration may be shown to be fallacious.

A machine traveling in the air is in the same position as a boat in a river. The current will carry the floating body along with it, and the speed of the current must be added to or deducted from the propulsion to obtain the actual rate of travel. A still better simile is that of a fly flying about the air inside of a railway carriage.

If an aeroplane be traveling through the air at 30 miles an hour, and if a wind be blowing at 20 miles in the same direction, it is easy to realize that the machine will be going at 50 miles an hour over the ground. So too, when it turns about and goes against the wind it will only proceed at 10 m. p. h. But what is not so easy to comprehend is as to how the machine will be affected if, when traveling with the wind, the latter suddenly drops. It may

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*"Aeronautics" (London), June, 1910.

be supposed that the speed will at once be reduced to 30 miles over the ground, and so if another puff comes up from behind the speed will simply be again increased. The inertia of the machine will, however, have some effect and cause it to travel on at a greater speed for a short sace of time after the wind drops.

This impetus may even cause the aeroplane to rise, as it gives an increased speed through the air. Langley discussed this action in his "Internal Work of the Wind." When going against the wind and it suddenly ceases to blow, it is evident that the speed over the ground will increase, but the inertia would probably act in such a way as to reduce the speed through the air, and the machine would consequently have a tendency to fall.

Then there is the question of a *side* wind striking an aeroplane. Some seem to imagine that this will tip up one side and even upset the machine the same as if it were resting on its wheels or the ground instead of being poised in mid-air. This, of course, is quite wrong. So long as both the plane and the wind are horizontal the latter can have no tipping effect. In reality, directly the wind "strikes" the machine the latter will move off in that direction, there being no force to oppose it, and the aeronaut will not feel the slightest puff on his cheek. That is, again, setting aside any momentary effect of inertia.

When we come to consider the effect of upward or *downward* trending currents of wind—eddies and whirls—then we are getting to another matter that *may* affect the stability to some extent. It an up-trending current strikes the front of an aeroplane it will affect it in the same way as if the horizontal inclination of the machine were altered, and will cause a shifting of the center of pressure. Thus, if the plane be driven horizontally while at an inclination of 5° and at the same time be struck by a puff of wind having an upward trend of 5°, it will be equivalent to the plane meeting the air at an inclination of 10° (*vide diagram*). But the less the inclination the more does the centre of pressure move forward, so that this would imply that the pressure is moved further back on the plane. As the centre of gravity is not altered this would form a couple tending to cause the machine to tip forward.

If a wind blows in an upward direction on the side of a machine it might have some tendency to raise the outer wing-tip, but it must be remembered that the wind is probably blowing at a rate of some 30 or 40 ft. per second (if strong enough to have any appreciable effect), which means that before it has had time to act on the tip it has passed on to strike the centre and the lee wing. Moreover, a puff of wind does not strike like a sledge hammer; it may come with force, but it comes gradually and takes appreciable time to attain its maximum. The effect would therefore be at most a "wobble," or slight roll such as may frequently be observed when birds are soaring in a wind.

We may now consider more closely the effect of inertia. The fly in the train will not be violently thrown against the side of the carriage when the train stops because its mass, and consequent inertia, is so small. And it is just this great difference in weight that should favor the large aeroplane flying in a strong wind. A gnat is at once blown away by the gentlest breeze, while a gull can battle against a gale. But there is as much difference in weight and size between an aeroplane and a gull as there is between the latter and a gnat. This leads us to hope that when airmen have had real experience, and machines are constructed in accordance with that experience, there will be no difficulty in combating the fiercest of gales.

TURNING IN A WIND.*

Two velocities must be borne in mind, that of the machine relatively to the air, and that relatively to the earth. The former is limited at its lower value to the flying speed of the machine, and the latter must be considered on account of the momentum of the machine as a whole. Change of momentum is a matter of horsepower and time, and it is this that is the ruling factor in flying in a wind on a circular course.

Suppose the flying speed of a machine is a minimum of 30 miles an hour relatively to the air, and a wind of 20 miles an hour is blowing. The actual speed of the machine relatively to the earth in flying against the wind will be 10 miles an hour.

If it is desired to turn down wind, the speed of the machine relatively to the earth must be increased from 10 miles an hour to 50 miles an hour relatively to the earth during the turn, and a corresponding change of momentum must be overcome. There are two ways of accomplishing this, either by opening up the throttle to give maximum power or by rising in the air previous to turning and swooping down as the turn is made, thus utilizing the acceleration due to gravity to assist the motor. The wind velocity will assist the machine also, as during the turn she will make considerable leeway, a small amount of which must be deducted to counteract the centrifugal force of the machine.

Turning in the contrary direction requires considerable skill, as when flying at 50 miles an hour the tendency on rounding the corner into a 20 mile an hour wind would be for the machine to rise up rapidly in the air. The centrifugal force, too, at these speeds is considerable, causing the machine to make much leeway with the wind during the turn. Turning under these circumstances should be commenced early, particularly if there are objects in the vicinity, and considerable skill should be acquired before an attempt is made to fly in such a wind.

Early flights should be commenced when the air is practically still, as it will be seen that difficult problems present themselves when a wind is blowing, particularly with heavy machines, and in cases where the engine power is comparatively small.

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*From "The Art of Aviation," by Robert W. A. Brewer. Page 209.

DETERMINATION OF MEAN RADIAL READINGS FROM ROUND PATTERN CHARTS.

C. W. MORGAN, JUN. W. S. E.

Presented April 5, 1911.

In the issue of *Power* for March 3, 1908, page 330, Mr. A. V. Youens presented a method of determining mean radial readings of round-pattern charts with a planimeter, which was proven erroneous by Mr. F. R. Swift in the issue of April 28, 1908.

The following is a solution for the same problem which the writer believes is exact for round-pattern charts with straight radial *time* lines, and if not exact, it is at least a close approximation for those having *curved* time lines. This method necessitates the use of a planimeter and a very simple instrument shown in Fig. 4, which is termed a *minograph.* The function of this instrument is the construction of a small figure within the orignal chart line, the area of which is requisite before the average reading of a chart can be calculated.

As there are two propositions which may be met in connection with round pattern charts, namely the determination of the average reading of an entire chart and that of a specific portion of a chart, two formulae have been deduced, that applicable to the latter problem being merely a simple modification of the formula for the solution of the first.

Formula for the Mean Reading of an Entire Chart.

$$M = \left(\frac{A\text{-}a}{2\pi r} - \frac{r}{2}\right) k$$

where:—

M = Mean reading of an entire chart in units of the chart, as, for example, on a recording steam gage, pounds per square inch.

A = The area within the original chart line as determined with a planimeter.

a = The area within the figure drawn with the minograph.

r = The radius of the zero circle of the chart.

k = A constant which is the equivalent of one unit of radial distance (inches or centimeters) in the units of the chart, i. e. (following the previous example of a recording steam gage) 100 pounds per square inch per inch of radial distance.

Formula for the Mean Reading of a Specific Portion of a Chart.

$$M' = \left(\frac{A'\text{-}a'}{2\pi r} \times \frac{m}{n} - \frac{r}{2}\right) k$$

where:—

M' = Mean reading of a specific portion of a chart in the units of the chart.

A' = The area within the original chart line and two radial lines which are the limiting time lines of the specific portion of the chart to be considered. For example, referring to Fig. 6, in which the average reading for 5 hours on a 24 hour chart is to be determined, $ABCO$ is the area A'.

a' = The area of $OMRSTN$ of Fig. 6. Lines OMR, and ONT are obtained by passing the tracing point T of the minograph along AO and CO respectively, and the line RST by passing the tracing point along ABC.

r and k are the same as in the preceding formula.

$\dfrac{m}{n}$ = The reciprocal of the fractional part of the entire chart being averaged. In Fig. 6, $\dfrac{m}{n}$ equals $\dfrac{24}{5}$.

Let us now consider the application of the first formula to the chart shown in Fig. 1, which has straight radial time lines and a *zero* circle with a radius of r inches. The first operation in the solution of this problem is to construct the minograph. This instrument can be made from celluloid, cardboard, or other thin material. Referring to Fig. 4, XY is a slot and P a pinhole made as close as is practicable to the end of the slot. The distance from P to T is made equal to r. Having constructed the minograph, the next operation is to draw the inner auxiliary figure shown shaded in Fig. 3, where for simplicity all unnecessary lines are eliminated. To draw this figure, place a pin in the slot XY and set it at the center of the chart. Then with a sharp pencil inserted in the pinhole, trace around the chart keeping the tracing point T continually on the original chart line. The figure traced by the pencil is the auxiliary figure desired. We are now prepared to determine the value of A and a either separately or combined as they appear in the formula. With an ordinary polar planimeter, it simplifies the solution considerably if the value A-a is determined in one operation. To do this, take the reading of the planimeter at the starting point S, trace in a clockwise direction around the original chart line, then pass in and around the inner figure in a counter-clockwise direction, and return to the starting point S along the same radial line. Again, read the planimeter and subtract the first reading from the second, the difference being the value of A-a. The determinations of the remaining quantities in the formula require no explanation.

In the application of the previous method of determining mean radial readings, to round-pattern charts with curved time lines, a minograph constructed as previously described is used.

June, 1911.

As will be seen later, no exact proof is offered for charts of this kind, therefore it is inadvisable to use this method where absolute accuracy is required, without first considering carefully whether the argument set forth for its use is reasonable or not. Graphical investigations by the author with charts having time lines of *small radii,* have shown only slight differences in their mean readings from those of straight time line charts showing the same fluctuations. All or at least a part of the difference in mean readings in each case may have been due to graphical errors.

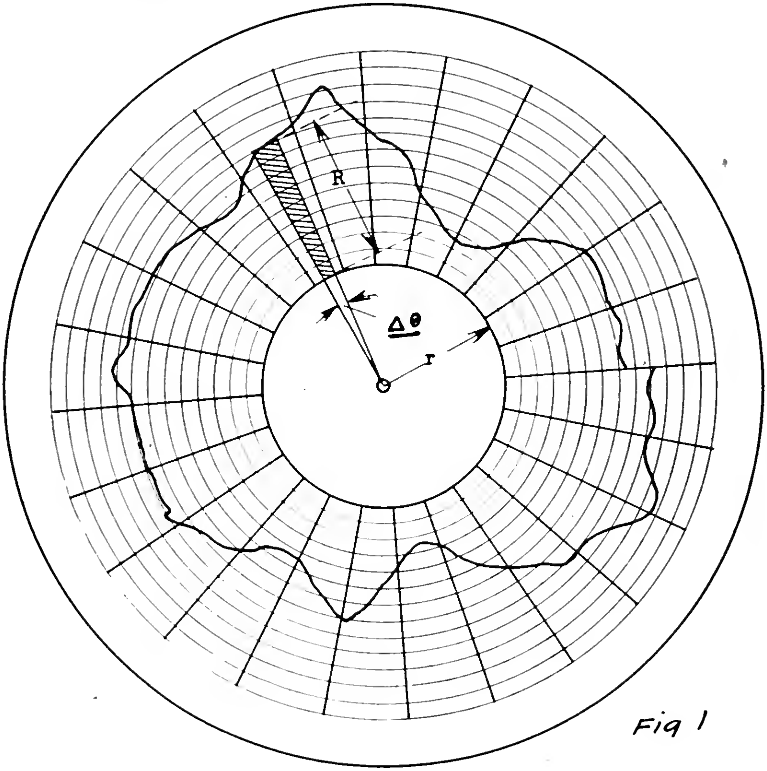

Fig 1

To simplify recurring determinations of average readings from charts of the same kind, which might be desirable wherever operating records are kept, one can very easily draw a curve on common coördinate paper plotting values of A-a against mean readings. As k and r are constants for the same style of chart, the formula for the mean reading is evidently the equation of a straight line.

Deduction of Formulae.

To give the reader a clearer understanding of the following deduction of the formula for the mean reading of an entire chart, the writer will outline the method used in the deduction. If we consider the area A within the original chart line of Fig. 1 as made up of a limitless number of infinitesimally small trapezoids (one of which is indicated on the drawing) and the zero circle, we find that the expression for this area may be transformed into an equation containing four terms. One of these is the area A, another the area of the zero circle, a third the area a drawn with the minograph, and the remaining term the area of the rectangular diagram showing the same fluctuations as the round-pattern chart. It is evident that if we now divide the equation under consideration by the length of the rectangular diagram just mentioned, the term expressing this area is replaced by its average height, which is the desired mean radial distance of the original chart. By transposition of terms and the introduction of the constant k, the formula already presented is obtained.

The following is the complete mathematical deduction of the formula:

Assume a round-pattern chart with the zero circle of radius r, and with straight radial time lines as shown in Fig. 1. Next divide the area within the irregular chart line, excluding the zero circle, into infinitesimally small parts, each of which may be considered as a small trapezoid of variable height R and with parallel sides of length $r\,\Delta\theta$, and $(r+R)\,\Delta\theta$, where $\Delta\theta$ is an infinitesimally small angle measured in radians. Now if n, the number of trapezoids into which the area has been divided, be allowed to increase without limit, the area A within the original chart line may be expressed in an equation as follows:

$$\text{I.}\quad A = \underset{n=\infty}{limit} \sum_{\theta=0}^{\theta=2\pi} \left\{ (r\,\Delta\,\theta) + (r+R)\,\Delta\,\theta \right\} \frac{R}{2} + \pi\, r^2$$

where $\left\{ (r\Delta\theta) + (r+R)\Delta\theta \right\} \frac{R}{2}$ is evidently the area of the trapezoid shown shaded in Fig. 1. By multiplying through the summation by $\frac{R}{2}$ this form of the equation may be obtained:

$$\text{II.}\quad A = \underset{n=\infty}{limit} \sum_{\theta=0}^{\theta=2\pi} r\,R\,\Delta\,\theta + \underset{n=\infty}{limit} \sum_{\theta=0}^{\theta=2\pi} \frac{R^2\,\Delta\,\theta}{2} + \pi\, r^2$$

It is now requisite for us to determine the meaning of the first two terms of the second member of the above equation. To explain the first of these, let us lay off a rectangular diagram of length equal to $2\pi r$ which will accurately represent the variations indicated on the chart of Fig. 1, as in Fig. 2. By subdividing this area into small strips, each trapezoid in Fig. 1 may be considered as having a corresponding rectangle in Fig. 2, with the same height R and a width equal to $r\Delta\theta$. Then the total area B of this diagram may be expressed thus:

$$\text{111.}\quad B = \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\pi} (r\Delta\theta)\,R = \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\pi} r\,R\,\Delta\theta$$

Again, referring to equation II, it is evident that the first term of the second member represents the area of the corresponding rectangular diagram, and hence we may substitute B for it, giving the equation:

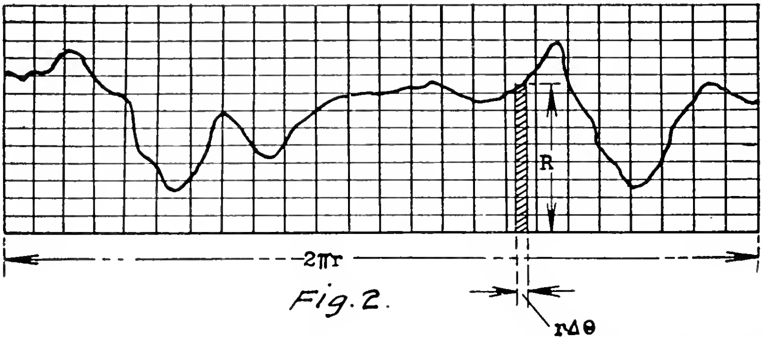

Fig. 2.

$$\text{IV.}\quad A = B + \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\pi} \frac{R^2\Delta\theta}{2} + \pi r^2$$

or by transposition:—

$$\text{V.}\quad B = A - \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\pi} \frac{R^2\,\Delta\,\theta}{2} - \pi\,r^2$$

To explain the remaining summation in equation V, an auxiliary figure must be drawn in the following manner: Along the radial lines in Fig. 1, plot points at a distance *r*, toward the center from the original chart line, thereby obtaining the small figure shown shaded in Fig. 3. Reasoning as before, we may consider the area *a* of this figure as the limit of a summation of infinitesimally small triangles. Expressed in an equation, it is:

$$\text{VI.}\quad a = \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\pi} \frac{(R\,\Delta\,\theta)\,R}{2} = \lim_{n=\infty} \sum_{\theta=0}^{\theta=2\,\pi} \frac{R^2\Delta\,\theta}{2}$$

Therefore, by substituting this value in equation V, we obtain:

VII. $B = A\text{-}a\text{-}\pi r^2$.

It is evident that if B be divided by $2\pi r$ (the length of the rectangular chart), we have as a result the mean ordinate *h*, which is the same as the mean radial distance desired,

or, VIII. $h = \dfrac{A\text{-}a}{2\pi r} - \dfrac{r}{2}$

Multiplying this equation by *k*, the constant previously mentioned which is the equivalent of one unit of radial distance in the units of the chart, we have:

$$\text{IX.} \quad M = \left(\frac{A-a}{2\pi r} - \frac{r}{2}\right) k$$

As has been previously mentioned, the author is unable to offer any exact proof why this formula may be applied to charts having curved time lines, hence he submits the following for criticisms and suggestion by the readers:

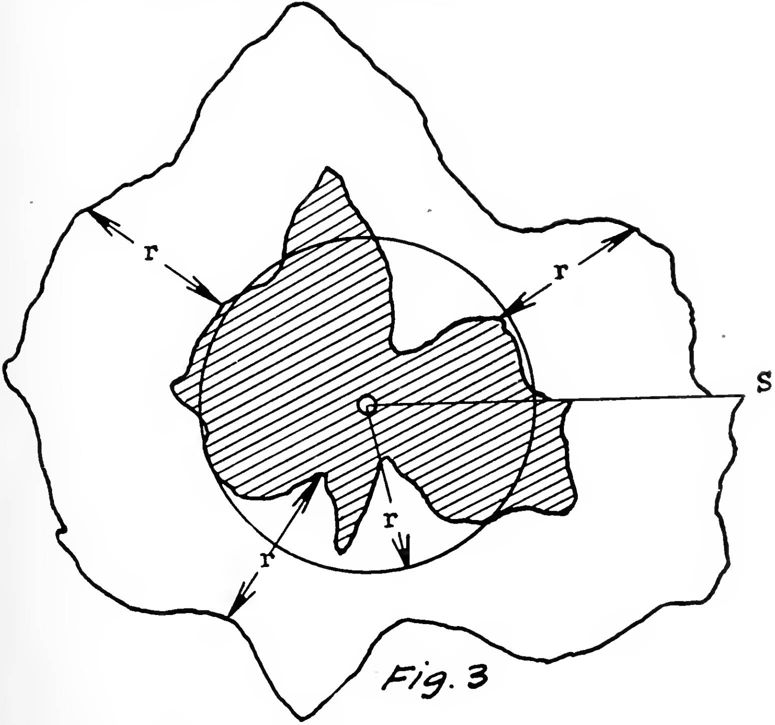

Fig. 3

Suppose we have two portions of curved and straight radial line charts superimposed as shown in Fig. 5. If these portions be considered infinitesimally small, the portion *BC* of the curved radial line chart may be considered straight, and also the portion *FC* of the straight radial line chart. It is self-evident that the curved sided triangular figure *OEACD* is equal to the triangular figure *OAC*. Triangles *ABC* and *AFC* are equal, as they have a common base *AC* and equal altitudes. Therefore the corresponding portions of the two styles of charts are equal. Hence it is logical to conclude that the areas *A* for the two charts are equal. A demonstration analogous to the preceding may be used to show the equality of the portions drawn with the minograph and indicated in light lines on Fig. 5.

June, 1911.

The formula for the mean reading of a specific portion of a chart was deduced in a manner similar to that for the mean reading of an entire chart, hence it has been omitted.

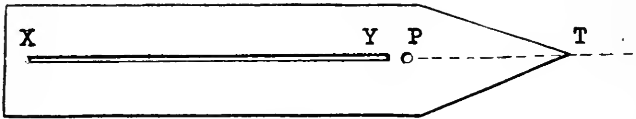

Fig. 4.

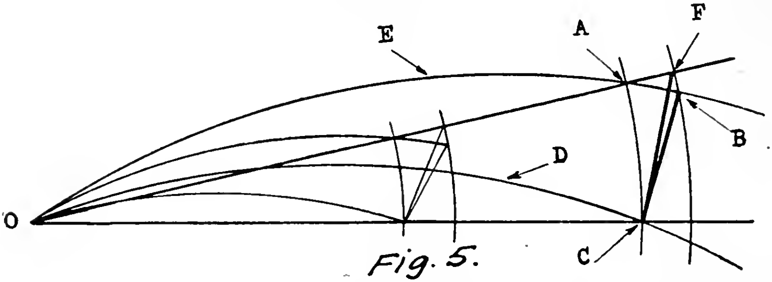

Fig. 5.

Referring again to Fig. 6, it is quite evident that if the chart was one with straight radial lines, the lines *OMR* and *OA* would be coincident and also the lines *ONT* and *OC*. This of course would simplify the determination of the mean reading of this portion of the chart.

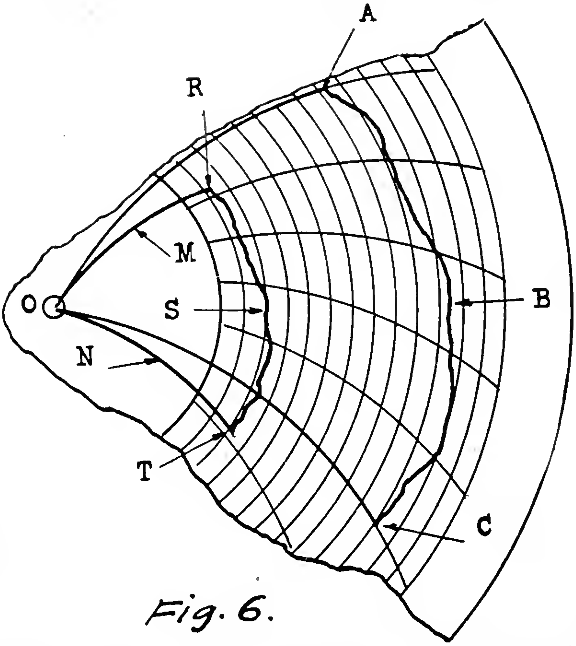

Fig. 6.

CEMENT STOCK HOUSES.

Josiah Gibson, M. W. S. E.

Presented March 8, 1911.

In order to provide for the seasonable variation in the consumption of Portland cement, every large plant must have a stock house in which to store the cement in bulk previous to bagging for shipment. The greatest demand occurs during the summer months, and to provide for this demand and secure the greatest economy of production, some cement plants run throughout the entire year, and the winter surplus is stored in stock houses.

Like all other structures used in the production of Portland cement, stock houses present many new problems to the designer. These problems have been met in a variety of ways, a few of which will be briefly outlined in a history of the manner in which the storage proposition has been handled in plants Nos. 2 to 5, inclusive, now in operation, and in plant No. 6, which is now being built by the subsidiary companies of the United States Steel Corporation.

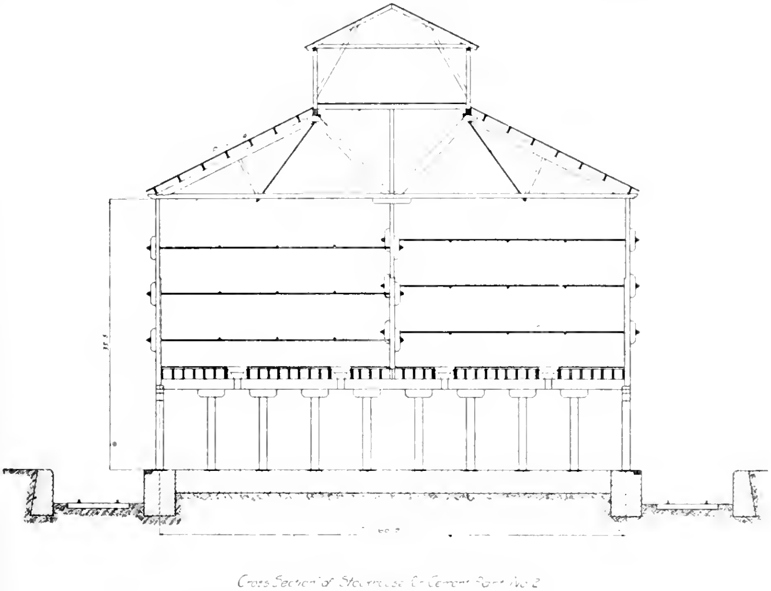

Fig. 1.—Wood Construction Stockhouse, South Chicago.

In the year 1899 a Portland cement plant was built by the Illinois Steel Company at South Chicago, having a daily output of about 2,000 bbl. The stock house has a storage capacity of 55,000 bbl. This stock house has sides of wood cribbing with brick veneer, the interior floors and roof trusses being of wood and of a type known as heavy mill construction. It has a span of 61 ft., a length of 168 ft., and a height of 35 ft. 5 in. from ground floor to lower chord of trusses.

The storage space was provided on the second floor and was divided by partitions into sixteen separate compartments. The pressure on the side walls and interior partitions was resisted by rods running transversely and longitudinally through the building, the rods being spaced about 6 ft. apart. Cement was taken into the building through the monitor floor and was taken out through hoppers at the bottom of the bins and bagged on the ground floor. This is shown in Fig. 1.

In 1904 cement plant No. 3 was built by the Illinois Steel Company at Buffington, Indiana. This plant has a daily capacity of 6,000 bbl. and is provided with a stock house having a capacity of 300,000 bbl. The stock house has a width of 100 ft., a length of 420 ft., and a height of 31 ft. from floor to lowed chord of roof trusses. It is of steel frame construction with reinforced concrete side walls, and is shown in Fig. 2.

The cement is taken into the building over belt conveyors to a monitor floor and dropped through screens into the main storage space below, from whence it is taken by screw conveyors through tunnels to the bagging rooms and bagged preparatory to shipping.

It will be noted that the steel roof trusses in this building are of the usual type, having a horizontal lower chord and an inclined top chord with the customary light web system between the two chords. In order to take care of the loads on the monitor floor, two central lines of columns were provided, these lines of columns being braced together in both directions by diagonal bracing.

The defects of this form of construction became apparent shortly after the building was put in use, and in order to understand these defects it will be necessary to describe a few of the characteristics of cement. When brought to the stock house from the finishing mill, the cement is a finely ground powder which weighs about 95 lb. per cu. ft. and is very warm and dry. Upon being dropped through the monitor floor to the space below, it becomes freely charged with air and acts much like a liquid, the top surface being almost level. After standing a few days its weight causes it to settle and form a closely packed mass, from which practically all the air has been expelled. This mass has some peculiar properties which have been found to be very destructive to the exposed members of the steel work.

Although the cement is as finely ground as flour, and slides freely on itself under ordinary circumstances, it has been found that, under the action of the screw conveyors underneath the floor, sections of the storage space may be emptied, leaving the balance stacked up in masses with almost perpendicular sides. These masses seem to stand for a short time, but finally collapse under their own weight and drive with great force against the side walls and interior members of the bins.

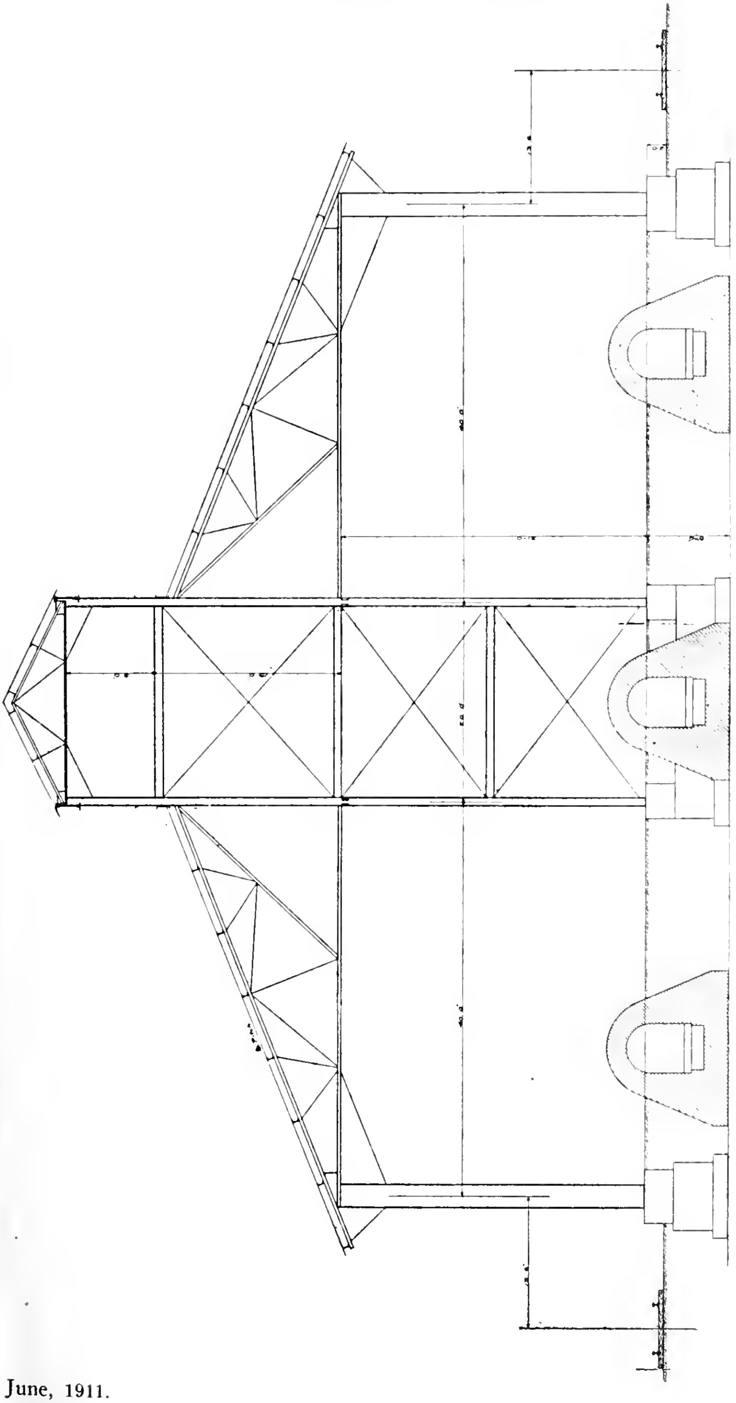

Fig. 2.—Plant No. 3. Steel Frame Construction, with Monitor Floor, Supported on Steel Columns. Buffington, Ind.

In the case of the stock house for cement plant No. 3, the interior columns were bent and twisted under the action of sliding loads, while the bracing in the lower chord of the roof trusses, and also some of the web members of the roof trusses themselves, were completely sheared off.

The knee braces, sections of the lower chord, and the upper section of the main column, showed the results of forces which were not previously known to exist in structures of this kind. The bracing between the columns was removed and the columns themselves were encased with concrete. In order to prevent the destructive loads on the members of the roof trusses, great care is now taken to avoid filling this stock house above the level of the lower chords of the roof trusses.

This building is still in service, but the dust arising from the cement continues to gather in masses on the roof trusses, and constant watching is necessary to see that the accumulation does not become large enough to endanger the strengh of the strucure. The principal lesson to be learned from this experience is that cement stock houses should be made so that the caking and sliding of the cement shall not be permitted to act directly on the lighter members of the supporting steel structure.

In 1906 the Universal Portland Cement Company took over the cement plants then being operated by the Illinois Steel Company, and in 1907 cement plant No. 4 was built at Buffington, Indiana. The stock house for this plant is 100 ft. wide, 560 ft. long, and 50 ft. high to the monitor floor, the total storing capacity being about 400,000 bbl. The side walls of this building were made of reinforced concrete. The upper reaction of the horizontal pressures against the side walls is transferred by heavy rafters to longitudinal girders extending between partitions placed every 60 ft. throughout the storage space. This is shown in Fig. 3.

Before designing the building, an elaborate series of experiments were made to determine the horizontal pressure of cement against the vertical side walls, and also to determine the increase of pressure due to the depth of the cement. It was decided that the building should be made to withstand a horizontal pressure of 10 lb. per sq. ft. at a depth of 1 ft., and an additional pressure of 10 lb. per sq. ft. for every additional foot of depth. In other words, it was to be strong enough to resist the action of a liquid having a weight of 10 lb. per cu. ft.

When the structure was first filled with cement, the side walls deflected to such an extent that the building was not considered thoroughly safe, and after the first load was taken out, the reinforced concrete pilasters were strengthened by interior reinforced concrete buttresses, the toes of which were attached to the unloading tunnels. The excessive deflection of the side walls of this building are supposed to have been due to the pressure exerted by the collapsing of large masses of the cement, which was much more

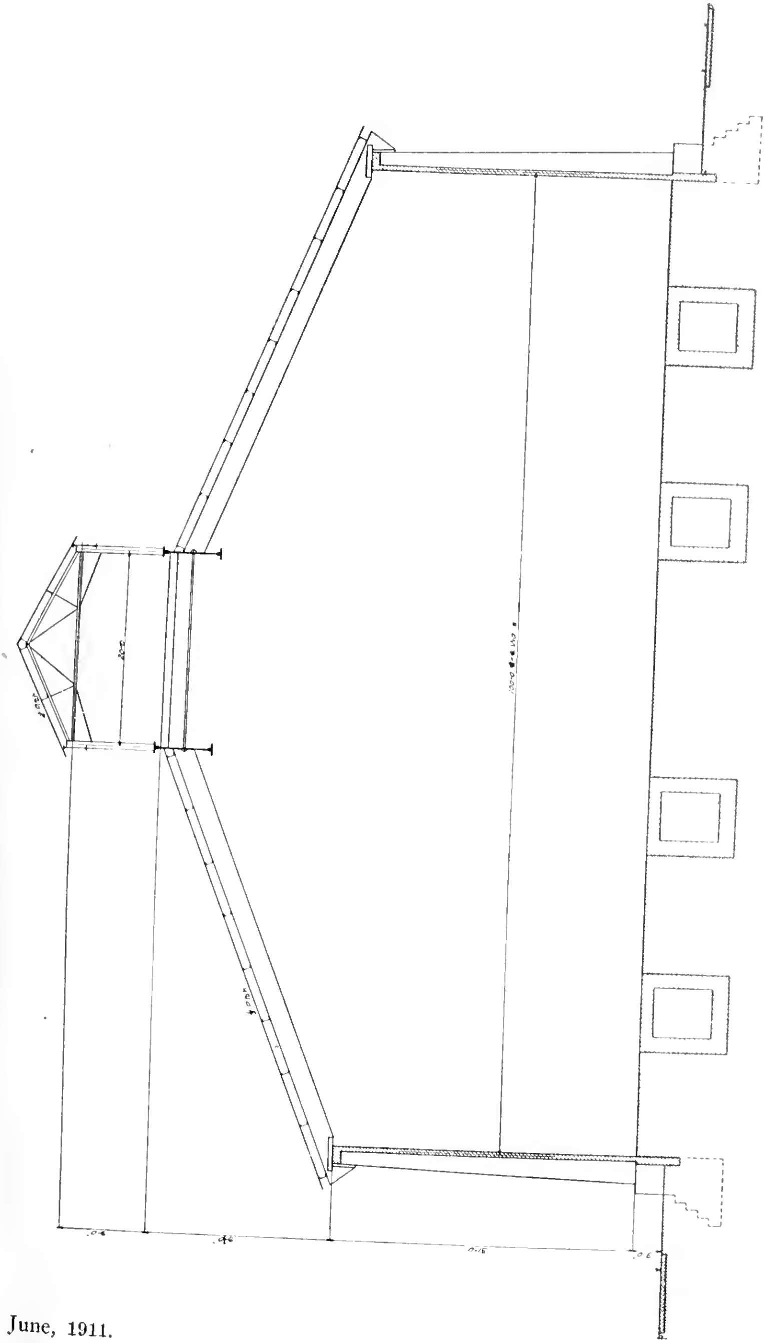

Fig. 3.—Plant No. 4. Reinforced Concrete Side Walls and Monitor Floor Supported on Longitudinal Girders.

destructive than the pressure which they were designed to resist. It was therefore decided to use a horizontal pressure of 20 lb. per sq. ft. for each foot of depth in the design of future structures of this kind.

Plant No. 5 was built in 1909 by the Universal Portland Cement Company at Universal, which is a small town near Pittsburg, Pa. The capacity of this plant is 12,000 bbl. per day. There are two stock houses, each having a width of 100 ft. The total storage capacity of the two stock houses is about 700,000 bbl. The side walls are made of reinforced concrete, supported by steel superstructures consisting of horizontal arch roof trusses supported on "A" frames having their perpendicular legs located in the plane of the side walls. These structures differ from the stock houses for plants Nos. 3 and 4 in the fact that there is no monitor on the roof trusses, the material being brought into the buildings over unloading floors which are centrally located in the planes of the elevated lower chords. It will be noted that very shallow roof trusses are used, thus producing high stresses and heavy members. This is to provide against the destructive loads from the masses of cement which accumulate on the exposed steel work.

The horizontal thrust against the side walls is resisted by the "A" frames, the interior legs of which are completely covered by concrete. No defects have yet developed in these stock houses, although they have probably not been long enough in use to afford a complete test of their strength and utility. See Fig. 4.

Plant No. 6 of the Universal Portland Cement Company is now being built at Buffington, Indiana. The design of the stock house for this plant is the main subject for discussion this evening. See Fig. 5.

This building has a span of 100 ft., and when completed will have a length of 1,000 ft. The total capacity of plant No. 6 is 13,000 bbl. per day, and the stock house when completed will have a capacity of about 800,000 bbl. The building, however, is being put up in two sections, the present section being 560 ft. long. It is this section only which will be described. It has a capacity of 480,000 bbl., and is made up of six storage bins each 60 ft. long by 100 ft. wide, four storage bins each 60 ft. long by 50 ft. wide, and two packing rooms each 40 ft. wide and 100 ft. long. The four small bins at the west end are used for storing cement which is subject to bin inspection. The large bins have a capacity of about 60,000 bbl. of cement and the smaller bins will hold about 30,000 bbl. each. This is shown in Fig. 6 and Fig. 8.

The steel work was designed in accordance with the specifications of the American Railway Engineering and Maintenance of Way Association, except that the customary unit stresses were increased by 25% for beams and columns which are completely surrounded by concrete. In the design of the reinforced concrete a modulus of elasticity of 30,000,000 was assumed for the reinforcing steel, and a modulus of 3,000,000 was assumed for the concrete, while a unit stress of 20,000 lb. per sq. in. was used for the steel and 750 lb. per sq. in. was used for the concrete.

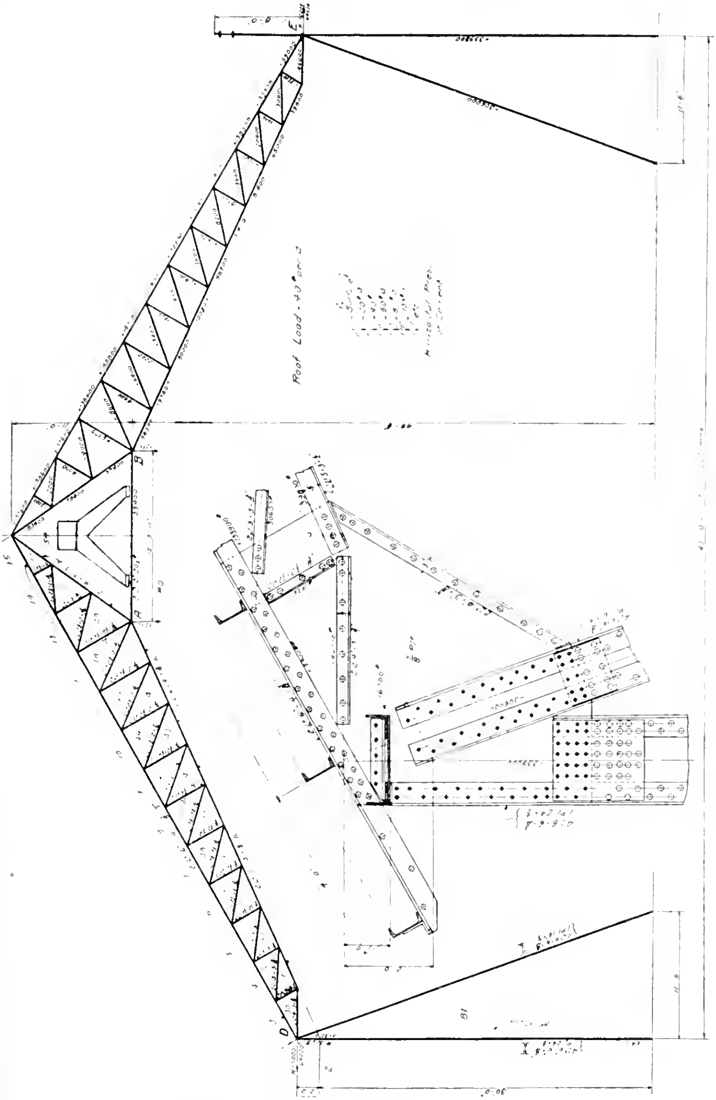

Fig. 4.—Stockhouse for Plant No. 5 at Universal, Pa.

The loads for which the building was designed were as follows:

(1) The dead load of the structure.
(2) A dust load on the roof of 20 lb. per sq. ft.
(3) A snow load on the roof of 15 lb. per sq. ft.
(4) Wind pressure due to a velocity of 90 miles per hour,

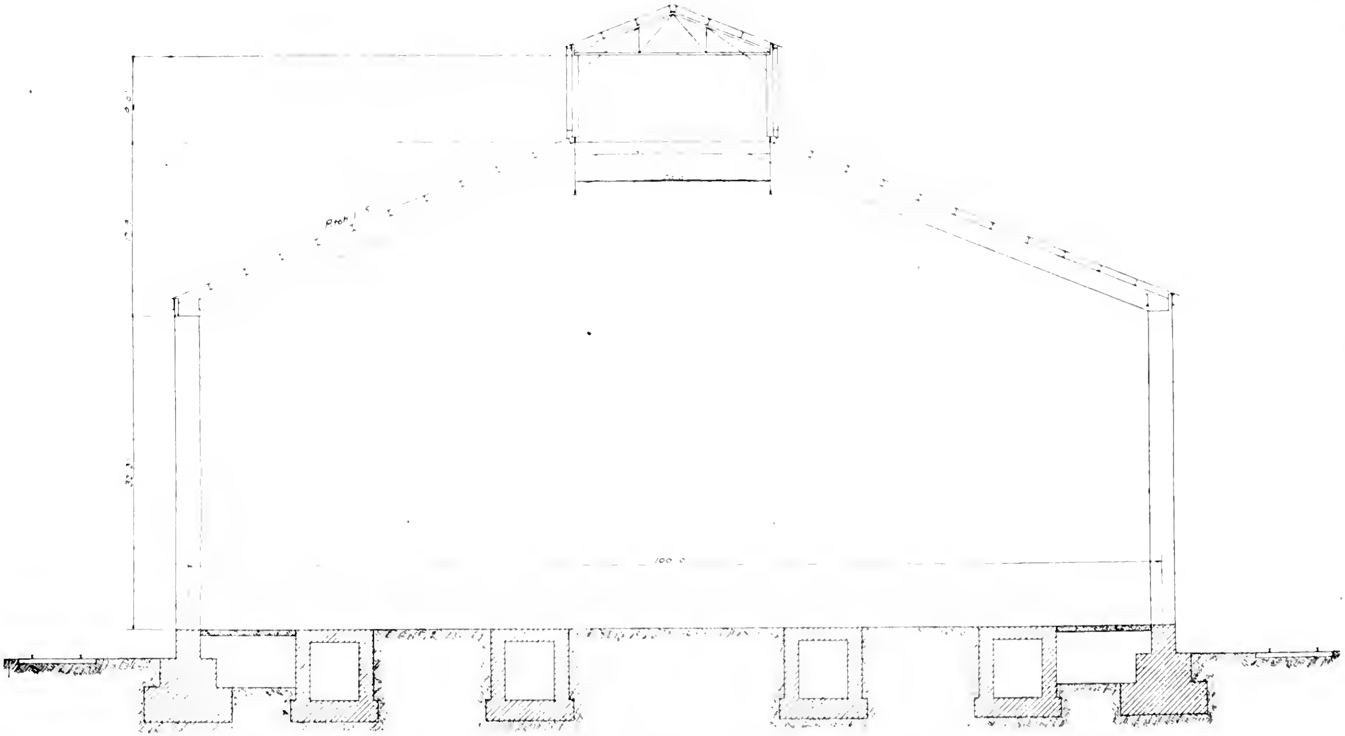

Fig. 5.—Stockhouse for Cement Plant No. 6, Buffington, Ind. Reinforced Concrete Side Walls, with Steel Columns.

or a pressure on vertical plane surfaces of 20 lb. per sq. ft. and 10 lb. per sq. ft. acting normally to the one-fifth pitch roof.

(5) The action of a full or partial load of cement weighing 95 lb. per cu. ft. and having a horizontal thrust equal in intensity to that of a liquid weighing 20 lb. per cu. ft.

The cement stored in each of the 60 ft. bins weighs about 11,000 tons, and the total weight of all the cement that can be stored in all the bins is about 90,000 tons. The total ground area of the storage space is 48,000 sq. ft. It will be seen that the above weight produces a load on each square foot of bin floor of about 2 tons. Considering the horizontal action of the cement as given above, it is found that the total bursting force, or, in other words, the force which tends to push out the side walls, is 12,480 tons. One-third of this force, or 4,160 tons, is transferred by the side walls to the roof system, and the remaining two-thirds, or 8,320 tons, is transferred by the side walls directly to the foundation.

The side walls are of reinforced concrete supported by vertical steel columns. The main columns are spaced 20 ft. apart and the intermediate columns are located midway between the main columns. The maximum pressure on these walls at the ends of the building is about 980 lb. per sq. ft., and at the sides of the building about 800 lb. per sq. ft.

Square reinforcing bars were used throughout; the main bars were placed horizontally, 6 in. apart, and temperature bars were placed vertically, 12 in. apart. The thickness of the walls in all cases is 12 in. at the bottom, 8 in. at the top, and 10 in. in the middle section. All the main side walls have columns with webs 30 in. wide, while the main partitions and end walls have webs 36 in. wide. In order to hold the horizontal reinforcing bars in their proper places, holes were punched in the web of all columns and all the bars were placed in position before starting to pour the concrete.

At the top of all walls the reinforced concrete is corbeled out so as to completely fill the heavy double-channel eave strut, and at the bottom of the walls they are corbeled out to the width of the foundations. The flange angles of the main columns show on both sides of the wall and the concrete is corbeled out to them, thus giving a fine paneled effect to all the outside walls. This is shown in Fig. 7, as also the steel framing of the bin partition walls.

The heavy outward pressure at the bottom of each of the main columns is resisted, by connecting the column bases with the tunnels which run beneath the floor by a reinforced concrete wall already shown on the foundation plan. A separate masonry plate is provided for leveling up on the concrete beneath the column bases. This masonry plate has an angle on each side at the top of the reinforced concrete walls, and the anchor bolts fit tightly through it. At the center of this plate is a 3 in. hole, through which the grout is poured after the plate is in position and carefully leveled.

The top re-action of the intermediate columns is transferred through heavy double-channel eave struts to the main columns, and thence through the main rafters, which are placed 20 ft. apart, to the monitor floor. This floor is thoroughly braced to take all the horizontal forces placed upon it by the main rafters.

DISCUSSION.

John Brunner, M. W. S. E. (Chairman): Mr. Gibson has pointed out to us in his paper this evening some of the problems which have presented themselves to the engineers designing stock houses for storing Portland cement in bulk, and has shown how some of these problems have been solved. In nearly all structures there is a period of development or experiment. During this period several different types of structures are tried. As the requirements of the structures, and the forces acting upon them, become better known the weaker types are gradually disposed of, and finally a type is developed that becomes a standard. It seems that the cement stock houses have gone through such a period of development during the last few years. Whether they have been evolved until a standard type has been reached, or not, only the future can show us. It is a very interesting problem and I trust it will bring out a live discussion.

Andrews Allen, M. W. S. E.: I was extremely interested in hearing Mr. Gibson's paper. The storage of masses of cement in such large quantities presents a great many unusual problems, and I shall take the liberty of asking a few questions. First, in regard to the action of that particular material in mass. How was the assumed amount of horizontal pressure arrived at? In the original plan a hydrostatic pressure was assumed from a substance weighing 10 lb. per cu. ft. That was afterwards increased, because of the failure of the original building, to 20 lb. per cu. ft. The material weighs actually 90 lb. per cu. ft., so that I am rather at a loss to understand why a 20 lb. hydrostatic pressure was assumed. Was this an assumption verified only by the fact that the structure stood up, or was it arrived at experimentally, and if so, how? This is one of the essential questions in the storage of many materials besides cement. In various kinds of coal many experiments have been made which have determined quite accurately the actual pressures at the different heights of that material. Of course, coal does not behave at all like cement. It seems to have a uniform angle of repose and it flows and arches quite differently from cement; but in the case of coal those things have been determined very carefully by expriment.

In store house No. 5 the author spoke of the cement being rehandled by means of cranes, and did not show how these cranes were arranged or supported. I would infer that the cranes must have a clear span of the entire width of the stock house, which would, of course, reduce the storage capacity.

With reference to storage house No. 6, where inclined rafters run through the longitudinal girders under the monitor, why was

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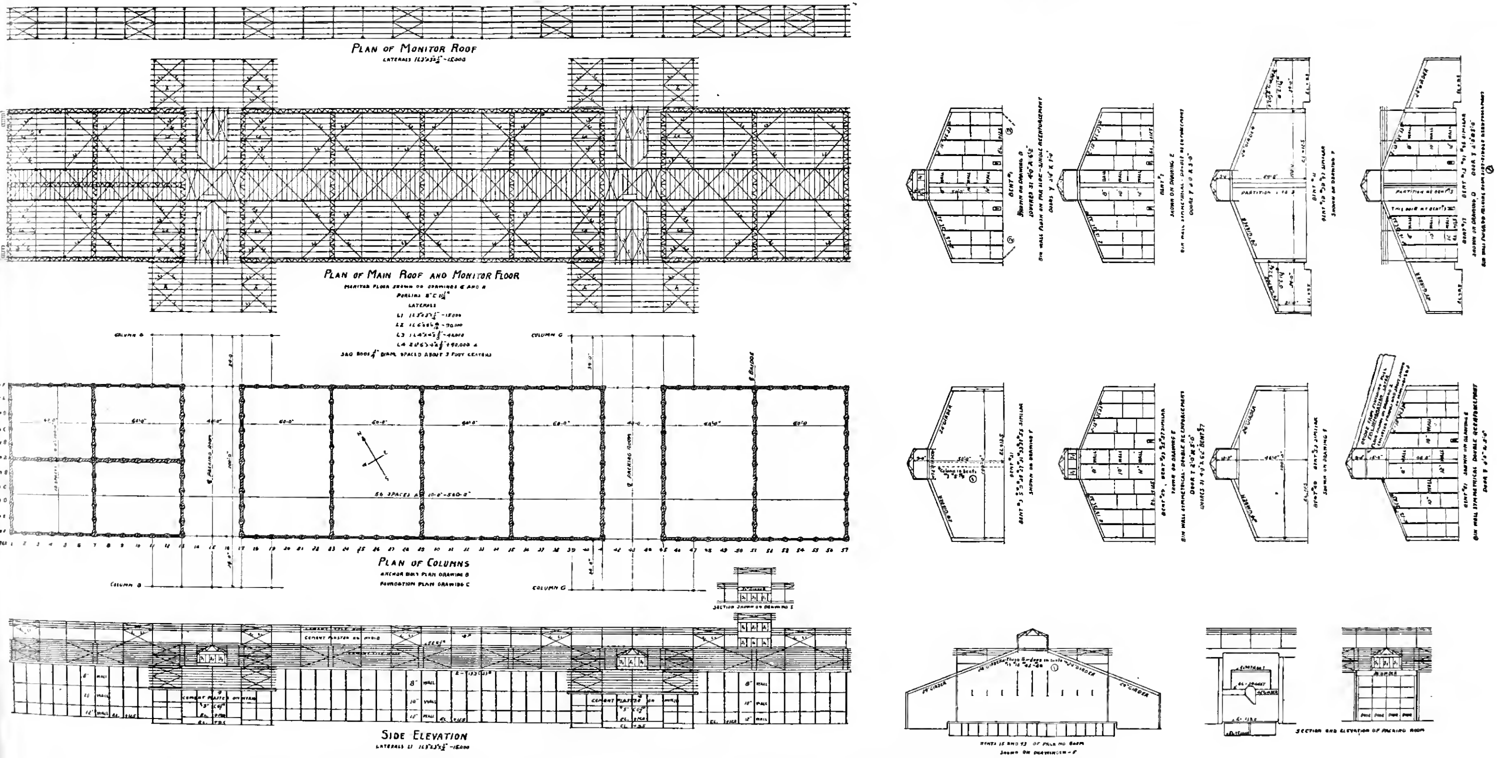
Plan of Monitor Roof
Plan of Main Roof and Monitor Floor
Column B
Column G
Packing Room
56 Spaces at 10'-0" = 560'-0"
Plan of Columns
Anchor Bolt Plan Drawing B
Foundation Plan Drawing C
Section Shown on Drawing E
Side Elevation
Section and Elevation of Packing Room

Fig. 6.—Cement Stockhouse for Cement Plant No. 6, at Buffington, Ind. Reinforced Concrete Side Walls, with Steel Columns.

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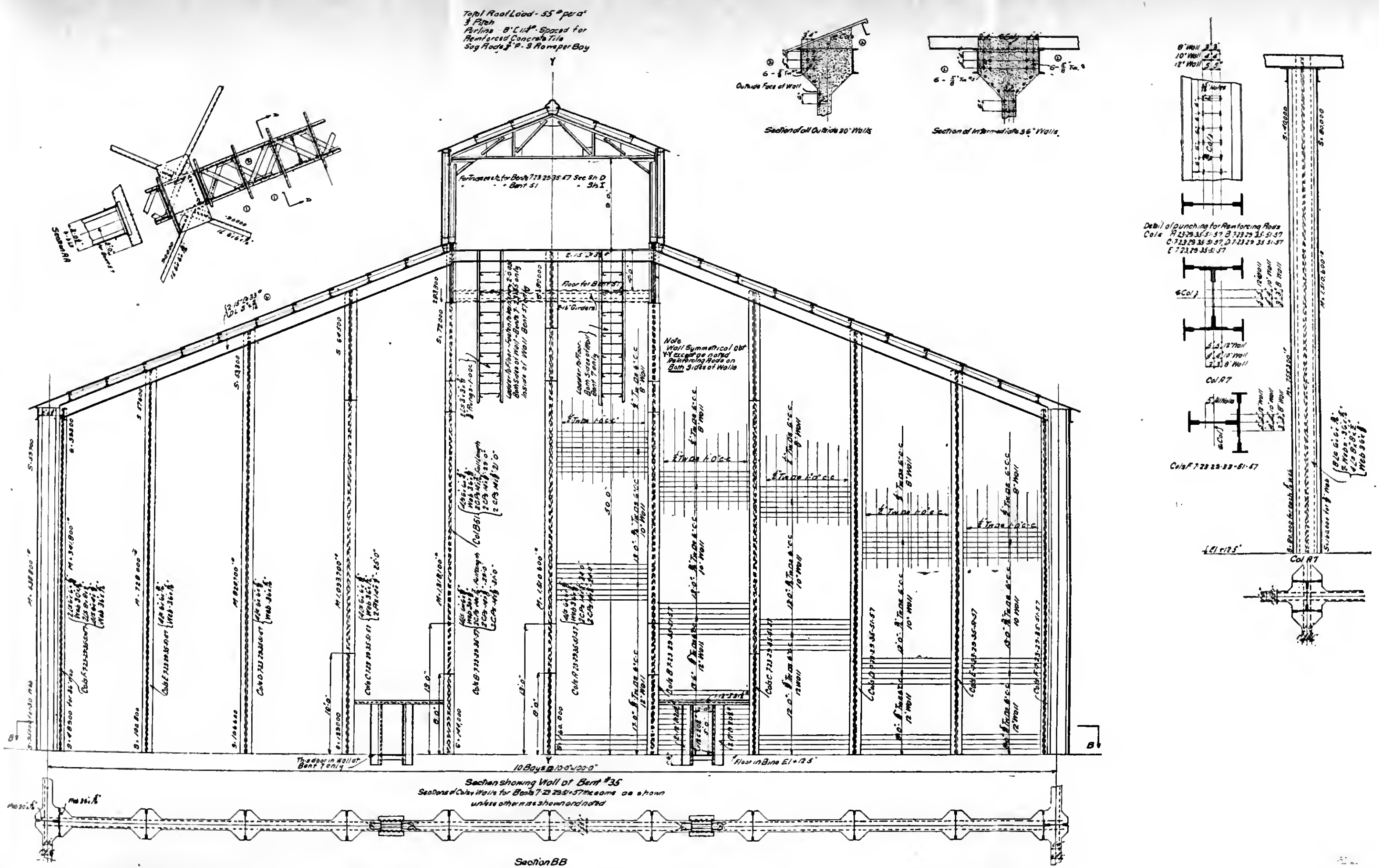
Total Roof Load - 55# per □'
⅓ Pitch
Purlins - 8" [11¼# - Spaced for
Reinforced Concrete Tile
Sag Rods ⅝" φ - 3 Rows per Bay
Y
Section of all Outside 20" Walls
Section of Intermediate 36" Walls
Section AA
Floor for Bent 51
Note
Wall Symmetrical abt. "Y" except as noted
Reinforcing Rods on Both Sides of Walls
Detail of punching for Reinforcing Rods
Col A7
Col F 7-23-29-35-51-57
10 Bays @ 10'-0" = 100'-0"
Floor in Bins El. + 12.5'
This door in Wall at Bent 7 only
B
Section showing Wall at Bent #35
Sections of Cols. & Walls for Bents 7-23-29-51 & 57 the same as shown
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Section BB

Fig. 7.—Cement Stockhouse for Cement Plant No. 6. Framing for Cross Partitions, Between Bins.

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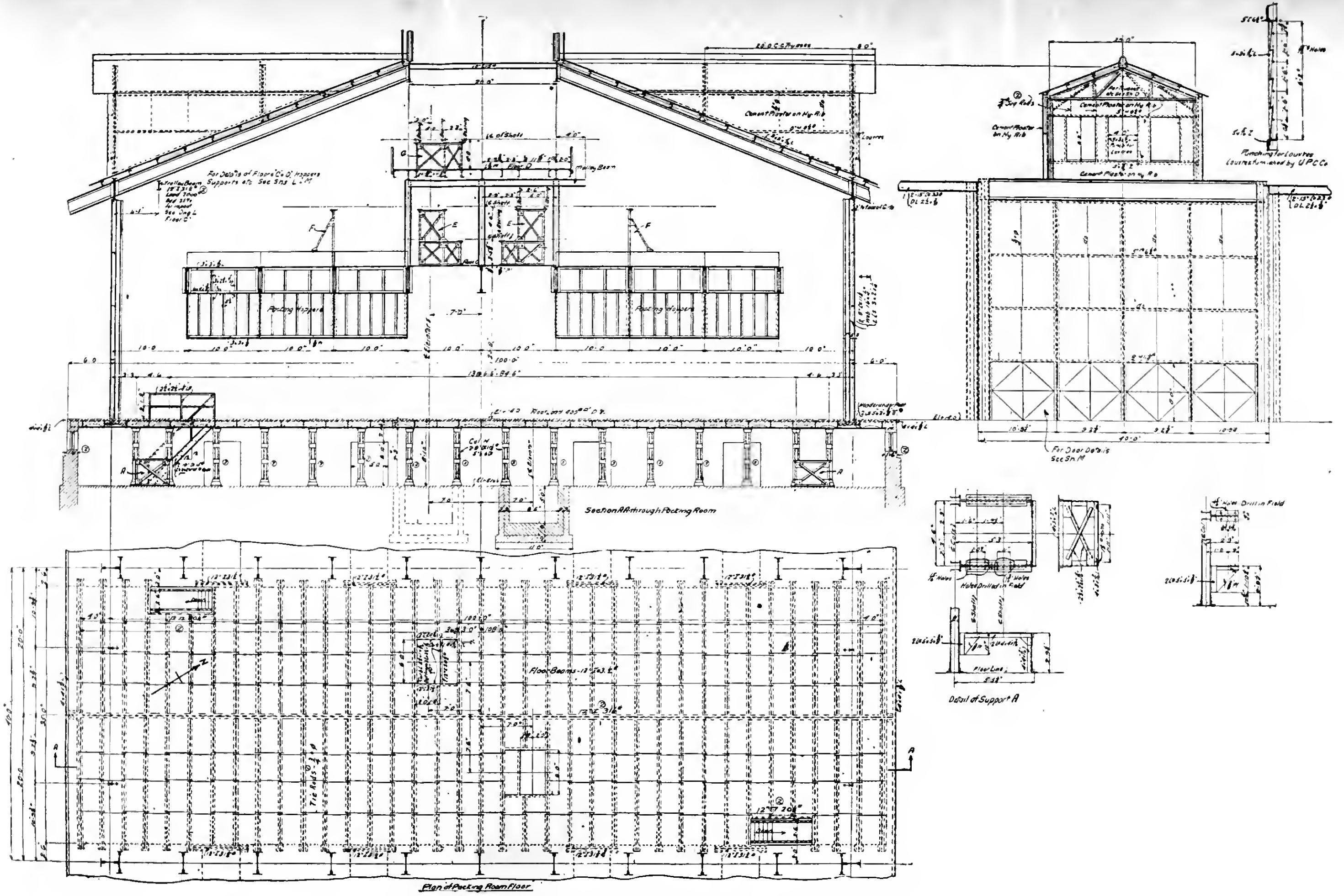

Fig. 8.—Cement Stockhouse, Plant No. 6. Showing Packing-room.

not a different form of construction adopted in place of the longitudinal plate girders? It looks to me as though the logical construction at that point would be longitudinal lattice girders encased in concrete, using a system of bracing which would allow a perfectly clear passage for the rafters to go through without cutting the web in two. This would be especially desirable on account of the light shear in the web, and you would doubtless save considerable metal besides making neater and simpler details.

Mr. Brunner: In regard to the first question, I will ask Mr. Carlson if he did not take part in the experiment made to determine the horizontal pressure at the time when the stock house for plant No. 4 was built?

A. G. Carlson: I was not present during the experiment, but I can probably explain how it was made. It was made in cement plant No. 3. Each cement house has a door, which was used as an entrance to the bin; inside this door several I-beams were placed. After these beams were in position, the cement was put in and the deflection was measured on the beams. We then figured back what pressure we got on those beams, and in that manner the load was determined, which amounted to 20 lb. per cu. ft.; we have been using that load since. I believe the angle of repose in that case is somewhere about 40°, although I am not sure. I do not remember the exact depth of cement we had at that particular time, but the bin was nearly full—about three-quarters full any way.

Mr. Brunner: Mr. Carlson can no doubt also answer the question in regard to the handling of the cement with crane in stock house No. 5.

Mr. Carlson: The crane in plant No. 5 is a crane in a way and yet not a crane. It is a bridge girder on which there is a trolley, and on that trolley an elevator is attached, which goes down to the bottom of the bin. In running, this elevator picks up the cement and it can also run back and forth on the bridge. The bridge can be moved longitudinally over the stock house, picking up the cement as it moves along. The elevator dumps the cement in a screw conveyor on top of the bridge, and it is then transferred to another stationary elevator, which takes it up to the belt on the monitor floor, or to the same belt that carries the cement into the bin. After it is placed on this belt it is taken over into the packing room, and then packed out from the packing room hoppers.

Mr. Brunner: I will ask Mr. Gibson to answer the third question, about using longitudinal plate girders in preference to lattice girders.

Mr Gibson: These girders are 60 ft. long. The loading points on them are 20 ft. apart, so there is a girder with two points of loading at the one-third points of the girder. Now, if we assume that only one point is loaded, the maximum shear in the center third of that girder would be one-half of what it would be in the end third of the girder, so at any time those girders have at least twice as much shear on the end third as they have on the center third.

As far as using the lattice girder is concerned, we think the plate girder is much better because it does not collect so much of the cement.

F. E. Davidson, M. W. S. E.: Some of the illustrations shown on the screen remind me of old times, particularly the illustration of cement house No. 3. I want to ask one or two questions, simply to refresh my memory.

My recollection is that the walls of the stock house No. 3 were made of concrete arches between the vertical steel girders; also that this was before we knew much about reinforced concrete and no attempt was made to reinforce the concrete between the girders. Am I correct, Mr. Gibson?

Mr. Gibson: Yes, there are arches.

Mr. Davidson: Then the question naturally arises, in designing the concrete walls for these stock houses, was any consideration given to the concrete as an arch? In other words, will not that one fact alone—if it is a fact that no attention was paid to concrete as an arch—probably explain why there have not been more failures on those walls under this very heavy loading which we now find comes from the sudden shocks of moving cement? In other words, you have designed the walls as slabs, for loads, equal to a load from a liquid weighing 20 lb. per cu. ft. You have absolutely disregarded the corbeling, which you speak of, of the concrete against the vertical girders. You have a 12 in. arch with 12 ft. span, and I think if a calculation is made you will find you do not need reinforcing bars.

I would like to ask Mr. Gibson something about the size of the bars, and if any attempt was made to hold them in position, or if they were simply spanned from column to column?

Mr. Gibson: I figured those walls as a simple span from column to column. Of course there is corbeling in there and we really get a stronger wall than we figure on. However, the reinforcing of the outside walls is only on one side of the wall, and I think if you allow much for the arch you ought to put in reinforcement on the other side of the wall also.

Mr. Brunner: Referring to the cross-section showing stock house for plant No. 3, the arches between the columns were not reinforced but were plain concrete arches.

Mr. Davidson: Have those arches ever shown any sign of failure?

Mr. Brunner: The arches have not, to my knowledge, shown any sign of failure. I had an opportunity to go through the stock house shortly after the failure had taken place in the bracing between the interior columns, and I found at that time that some of the transverse bracing angles were bent out of line and torn loose from their connections at the columns, and at the cross struts; also that the ends of some of the cross struts had been sheared loose from the columns. Some of the columns were bent several inches out of their true position. If I remember correctly, the failure took place after the stock house had been filled only once or twice.

Mr. Davidson: My recollection is that the failure in the stock house occurred after it had been filled the first time.

Mr. Brunner: The failure of the trusses did not take place until two or three years after the stock house had been put in operation. The stock house was at first filled to the bottom chord of the roof trusses and later was filled so that part of the roof trusses became imbedded in the cement. The bottom chord angles were sheared off on some of the trusses, and some of the knee braces were buckled and broken. The failure evidently came from a combination of the tensile stresses in the bottom of the chord caused by the outward thrust of the cement against the walls, and the bending caused by the cement which was piled on the top of the bottom chord. The trusses were repaired, and instructions were given to keep the top of the stored cement below the bottom chord of the trusses at all times. Since this was done no sign of failure has shown itself in the truss members. The columns were encased in concrete about 30 in. in diameter.

Mr. Davidson: I would ask why the type of construction of the concrete arches, as used in stock house No. 3, was changed to a reinforced concrete slab?

Paul P. Stewart, M. W. S. E.: At the time we started to design cement plant No. 6, the matter of the arch without reinforcement occurred to me. I carefully considered the construction shown for cement plant No. 3, and made some estimates of the amount of concrete which would be required for cement plant No. 6 on the same style of design. I also made comparative designs of a reinforced structure, and found that, while in the plan used in cement plant No. 3 a good deal more concrete was required, the other construction would require less concrete and some steel. After considering the two designs, I decided that the reinforced construction was the better of the two.

Mr. Carlson: Those arches have expanded metal in them, but I do not know what size.

Mr. Stewart: I failed to mention, in the comparison of two different styles of concrete side walls, that the cost of the form work, with the reinforced concrete flat-arch construction, is much less than that required by the arch construction. We know exactly what to depend on when we make a reinforced concrete wall, while with a concrete arch construction without reinforcement I believe we are using somewhat uncertain principles.

Mr. Davidson: In running over some calculations mentally, I do not see how you arrive at a 12 in., reinforced concrete slab for those walls with a 10 ft. span, using 750 lb. as the unit stress in the concrete in compression. I was wondering what factor of safety you used after you made those assumptions.

Mr. Stewart: I believe Mr. Gibson's paper gives the unit stresses used in the design of the structural steel work. We used 750 lb. per sq. in. compression on the concrete, and 20,000 lb. per sq. in. tension in the reinforcing material. By the use of the customary calculations we arrived at the sizes given by our design.

Mr. Davidson: That slab was figured with the formula, $M=\frac{Wl}{8}$, was it not?

Mr. Stewart: Yes, sir.

Mr. Davidson: You figured everything as a simple span. In this connection I would like to bring out a point. I have recently had occasion to make a test of a reinforced concrete slab under the direction of the city building department, and we got such astonishing results that I spent some time in doing some calculating to find out what was the matter with the design. As near as I can find out, instead of using $\frac{Wl}{8}$ we are authorized, and I think we are justified, in using $\frac{Wl}{10}$ for simple spans in reinforced concrete. In other words, the arching action of the concrete slab, if you wish to put it that way, is sufficient, and amounts to the difference between $\frac{Wl}{8}$ and $\frac{Wl}{10}$. I would like to hear some discussion along that line. These are actual figures which I made from a test yesterday on a reinforced concrete slab. The testing was done under practically laboratory conditions. I had the cement tested; the steel was tested; I knew what the elastic limit of the steel was, and what the cement was good for. The result I got from the actual tests and the actual loading showed that $\frac{Wl}{10}$ was the figure instead of $\frac{Wl}{8}$, as equaling the moment of resistance of the slab.

Wm. Artingstall, M. W. S. E.: The question whether to use $M=1/8\ wl^2$, $M=1/10\ wl^2$, or some other fraction of wl^2, depends a good deal on how the designer considers his beam or slab supported. If we have a single span with free ends, the bending moment for a uniformly distributed load is $1/8\ wl^2$ and nothing else; but if we have two or more supports, then the bending moment is something else, and the moment will be determined by whether beam (or slab) is a simple beam fixed at both ends or is continuous over two or more supports.

In the design for beams, it seems that we should adhere strictly to the theoretical analysis of the particular case with which we are dealing and design the beam either as free ended, or fixed ended, or continuous if it be an inside panel. In the majority of cases, there is no doubt but that the beams in an outside panel could be figured, using $M=1/10\ wl^2$, and we are perfectly justified in using $M=1/12\ wl^2$ for the interior panels. I do not believe in the use of a smaller value of M, for there is neither reason nor logic in doing so. I would rather increase the unit stresses in the material used, but where we are bound by prescribed loads and unit stresses in a building ordinance this cannot be done.

In the case of slabs, the question of what moment to use is not so simple as in the case of beams, and the design developed depends on how the engineer considers his slab supported. The Committee on Concrete and Reinforced Concrete of the American Society of Civil Engineers says: "Floor slabs should be designed

> as continuous over the supports. If the length of a slab exceeds 1.5 times the width, the entire load should be carried by the transverse reinforcement. Square slabs may well be reinforced in both directions."

And in a note they say—

> "The exact distribution of the load on square and rectangular slabs supported on four sides and reinforced in two directions cannot be readily determined. The following is approximate but safe:

$$\text{Distribution of Load}=r=\frac{L^4}{L^4+b^4}$$

L/b	r
1	0.50
1.1	0.59
1.2	0.67
1.3	0.75
1.4	0.80
1.5	0.83

r=portion of load carried by transverse reinforcement.

L=length of slab.

b=breadth of slab.

> Using the values above stated, each set of reinforcing may be calculated as for a slab supported on two sides, but the total amount of reinforcing may be decreased 25% by increasing the spacing of the rods from the third point to the edge of slab."

If we have a square slab (with beams and girders) reinforced both transversely and longitudinally, with sufficient reinforcing to provide for the negative moment over the supports, we can figure each set of reinforcement using $M=\frac{wl^2}{24}$ and in view of the fact that a certain amount of reinforcing is necessary in passing over the supports to prevent cracking of the slab, even if figured as free ended, it seems to me that we might just as well consider all slab construction as continuous and design accordingly. This will result in giving a stiffer construction if nothing else.

Where, however, we have a slab without beams, the question again reverts to, how is it supported? Shall we consider the slab as supported at four corners? Or shall we consider the slab around the head of the column as a cantilever out to the point of inflection, supporting a uniform load over its surface, and the remainder of the load distributed around the edge of the cantilever, as concentrated loads? Or shall we consider the slab as a flat circular plate out to the point of inflection, with a uniform load over its surface and the weight of the slab, plus the rest of its load, concentrated around the outer edges?

Grashof*, from his investigation of the end plates of boilers, considers the greatest bending moment in plates supported at the four corners as $\frac{wl^2}{26.5}$ per lineal foot, and Mensch in his Handbook says that by similar reasoning we can lay down the rule for girderless floors,—

> "Divide the panels in strips of a width equal to 0.35 l, where l equals the distance center to center of supports in feet (two strips run diagonally while the others run in the direction of the columns). The greatest bending moment of such a strip equals $\frac{wl^2}{20}$ when the size of the capital is at least 0.23 l. From this we can easily obtain the thickness and reinforcement."

Using $\frac{wl^2}{20}$, however, seems to be running rather close to the danger line, particularly when a slight change in the position of loading from that assumed in the design will often give stresses entirely different from those anticipated, and the excessive deflection shown in most of the flat slab construction should certainly compel the use of a more conservative value.

Mr. Allen: In discussing that wall of cement house No. 3, it occurred to me that a number of us will recollect the type of construction originated by Mr. Schaub, late Member of our Society, wherein he made a test of a 6 in. unreinforced slab, restrained on four sides, which stood, as I recollect it, a load of about 300 lb. per sq. ft. under test. Now, with the columns of 10 ft. section all the way through, it looks to me as though that was an ideal situation for walls of that kind, with a 6 in. unreinforced slab, the width of the column, 36 in.,—whatever it is,—making a sort of a flat arch, and with horizontal struts at certain intervals giving

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*Lanza's "Applied Mechanics."

that same effect vertically. That gives a very simple form of construction and avoids all reinforcing rods. Was that construction considered?

Mr. Stewart: No, I do not think it was, but the cost of forms required in the arch was one of the things that influenced us to use the construction that we did. The cost of reinforcing is a very small item in the total cost, and where the expense of forms is such a big item I do not think that the matter of reinforcing should be considered so seriously. I have made several comparisons of cost, and firmly believe that the construction we used is the cheaper and more conservative.

E. D. Martin, M. W. S. E.: Cement bins are a little outside of my practice, and I rather hesitate to differ offhand with the gentlemen who base their views on long study and experience. I do think, nevertheless, that the use of $\frac{wl^2}{8}$ for the computation of the bending moment due to the lateral forces acting against the concrete slab construction of the side and end walls is unnecessarily conservative. The condition of loading with respect to the intensity of loading on adjacent panels is uniform, and for that reason the full advantage of continuity over support may safely be taken. Taking this into consideration a rough calculation makes the thickness of concrete near the foot of the wall about 8 in. instead of 12 in.

Outside of the engineering features of the subject there is one phase of the matter that strikes me forcibly. The structures in question are those built by a cement company for the storage of cement. Would it not be good business for the cement company to show more faith in its own product by using more reinforced concrete and less structural steel?—do a little missionary work so to speak. In one of the later types of cement bins described by the author, the floor of the bin is of heavy steel construction supported on structural steel columns. I am certain that reinforced concrete could be substituted with economy, and in all of the buildings described reinforced concrete columns could advantageously replace the steel wall columns.

Mr. Stewart: We tried that form of construction in plant No. 4. It had to be reinforced further in order to prevent the dangerous bulging of the walls.

A. C. Warren, M. W. S. E.: The first type of storage elevator that the Illinois Steel Company had, consisted of four circular bins, some 90 ft. high. That seems to have been abandoned entirely. I would like to know why the type was changed.

Mr. Stewart: I examined those four circular storage bins in South Chicago, and they were all right except that the cost per cubic foot of storage was higher than in any other construction.

Mr. Brunner: That question of using the circular bins was taken up before the stock house for plant No. 3 was built, but they were found to be too expensive compared with rectangular bins and would take more space.

Ray S. Huey: I do not know that I can add very much to the discussion, although I have been present, I believe, at most of the failures of the cement stock houses discussed. Plant No. 3 was the first in my experience. I have been in the bins a good many times when they were full and when they were empty, and have noticed the changes which have occurred. As I recall it, when plant No. 3 failed the columns first were bent or kinked at the point where the struts that went across between the columns as braces were riveted. These struts bent down about 6 or 8 in.; later they bent as much as 18 in. and then broke off. Of course, the bending changed the shape of the columns entirely, causing a square turn, we might say, at the connection with the strut; owing to the sharp bend at the connection, the portions of the column above and below this connection were forced out of the vertical line. Then we took out those columns and attached the struts to the bin walls with big, heavy brackets, getting rid of the columns entirely in those bins. On account of the bins being loaded in and out so frequently, we did not want anything in the way. The stock houses as a rule are loaded up clear into the roof truss. It depends, of course, on the season of the year. In the winter time the stock house is nearly full. As the season is not then open, it is often necessary to overload the bins or shut down the mill. I have seen the cement within 3 ft. of the roof truss all the way along the full length of the bin and down at the end wall, covering the wall up to the roof. The angle on which the cement runs I think is not over 10°; so when it begins to get full it piles up against the roof itself and fills up over the truss. In stock house No. 3 right now I think there are a number of the trusses that are bent in the same way, although to get around that we extended the chutes from the monitor floor down to within about 3 ft. of the bottom chord of the truss; so we never get much over 3 ft. above the chord now. In plant No. 4 we had an entirely different experience. Some of the reinforced concrete pilasters broke under the strain. These were reinforced by plates on the outside and on the inside, bolted through. The pilasters were also braced in the bottom by a bracket of reinforced concrete. Stock house No. 6 looks as if it would be all right.

Sidney J. Robison: There is one thing I will speak about, in regard to figuring upon the size of those walls and taking the bending moment $\frac{Wl}{10}$ and $\frac{Wl}{12}$. When one is figuring on loads that probably occur in a stock house, and looks back to a plant that is not very far away and knows that one bin has failed here, and then goes into another stock house and sees pilasters in the walls sheared off and also failing under bending, there is a desire to use $\frac{Wl}{4}$ rather than $\frac{Wl}{12}$ when making the design. When the structure is once up and the engineering is forgotten, if the structure always stands one feels that the engineering will not be criticised as it would be if the structure failed in the course of two or three years. In regard to the walls of stock house No. 6, as they are now constructed, I believe that at least $\frac{Wl}{10}$ would be a safe figure on the bending moments, because the reinforcing is practically continuous. As the rods were detailed, every other rod in the wall runs completely through a column and to the next one; in other words, the joints are staggered so that in all probability $\frac{Wl}{10}$ would be, as the wall was finally constructed, a perfectly safe figure in considering the reinforced concrete.

Mr. Brunner: I will ask Mr. Carlson if he has ever noticed any expansion cracks in the long side walls of the stock house?

Mr. Carlson: There are some cracks in plant No. 4. Whether they were caused by expansion or by failure I really do not know; but in many of the panels there are cracks. That is something we have not made tests of or examined closely.

R. F. Smith: I would like to know with what success the method of handling cement in plant No. 5 is meeting; how does it compare with the system of tunneling?

Mr. Carlson: The method of handling cement in plant No. 5 so far seems to give satisfaction; but we are not yet able to say that it is going to be any better than the use of tunnels, because we have not used it enough to determine that fact.

Mr. Brunner: Have you used it long enough to determine how the cost will run, compared with the trussed system?

Mr. Carlson: No. We are using it now but have no figures to present. As far as the installation of the machinery goes, the use of the crane works satisfactorily.

W. T. Curtis, M. W. S. E.: Referring to the store houses where the tunnel is used, how is the cement removed from the storage between the tunnels? I should think it would pile up between the two tunnels in a sort of pyramid or ridge.

Mr. Carlson: It is removed by hand shoveling, about once a year.

Mr. Davidson: Mr. Gibson remarked in his paper that it was found that the action of the fresh cement upon the steel was very bad. I would like to inquire what that action was and how it affected the steel.

Mr. Brunner: I asked the same question myself when I first looked over the paper. Mr. Gibson referred to the destructive action by the bending of the steel which may become inbedded in the cement when the stock house is filled. There is, as far as I know, no chemical or corroding action.

Mr. Gibson: Referring to this question of action. After cement settles a few days all the air is forced out of it by the weight of the cement. Cement is being drawn from the bottom of that pile, and after a while there is a movement—a sudden movement. There is not only the weight of the cement, but also a suction from below that bends the steel, and it is not so much the weight above as the suction pressure from below that causes the wreck.

In regard to the reinforcement in those walls, the column separates the walls so that there are individual slabs. I think if one figures $\frac{Wl}{10}$ he must consider that he has a bending moment in the opposite direction. The end of the wall is fixed to a certain extent, and if there is a bending moment on that side, even figuring $\frac{Wl}{12}$, or $\frac{Wl}{10}$, one should put in reinforcement on that side of the wall to take care of those bending stresses. I think it is a much simpler proposition to put the reinforcement in on one side of the wall only, and if this is done I think where the slabs are individual slabs, any one of which may get a sudden load from a collapsing of the cement (it may not come over several slabs but on one), the safe way is to figure $\frac{Wl}{8}$.

Mr. Davidson: I agree with Mr. Gibson that $\frac{Wl}{8}$ is a conservative and safe figure, but I wish to raise the question at this time as to whether or not, in figuring a simple reinforced concrete slab, we are justified in using a bending moment of $\frac{Wl}{10}$ and not $\frac{Wl}{8}$, as is customary in figuring steel or timber. In asking that question I am asking it in all sincerity. I believe we are justified in using $\frac{Wl}{10}$ in figuring a simple reinforced concrete slab, and my reason for it is not only the tests which I have made personally, but tests which have been made by a number of investigators. It seems, when one comes to analyze the problem, that the simple reinforced concrete slab can be considered more or less as a restrained arch, and the additional strength is due to the arching action of the concrete itself, restrained by the reinforcement in the slab. I raise that question for future discussion or for discussion at this time.

Mr. Gibson: I understand that you do not refer to a continuous slab.

Mr. Davidson: No, I refer to a simple span, a simple slab.

Mr. Gibson: Your results may be due to the fact that the concrete will take pressure a great deal more than it is considered to take. Instead of taking as a safe load 750 lb., the concrete may be taking a safe load of, say, 1000 lb. per sq. in. That would make quite a little difference in the figures.

Mr. Davidson: But Mr. Gibson gets away from the fact that in figuring reinforced concrete, the steel must take all the tension. It is immaterial what the compression stress is in the concrete. I contend that in figuring the resistance of the slab we are justified in using $\frac{Wl}{10}$, and it is immaterial whether we assume 1000 lb. per sq. in. or 100; it is immaterial what we assume as a unit stress. Actual tests will give us about this result.

Mr. Brunner: Is it not a fact that care used in placing reinforced concrete determines its strength? There are several operations which must be watched. We have to watch that we get the reinforcing rods in their proper place, that we get the concrete properly mixed, and that it is properly placed. With these uncertainties which may creep in during the placing of the concrete, I would consider that it is better and safer to make it a little heavier than the test slabs would indicate, where there is a good strong concrete.

Mr. Davidson: Does not the same personal equation come in, say, in designing structural steel?

Mr. Curtis: I would ask Mr. Davidson, if in one of his earlier remarks, he said that he had arrived at the conclusion to use $\frac{Wl}{10}$ by a laboratory test?

Mr. Davidson: No, I said an actual test made on some slabs in a building. I believe that the Northwestern Expanded Metal Company did make a series of extended laboratory tests on the same lines, and arrived at the same conclusion.

Mr. Curtis: My point was, if that is based on laboratory tests one might not get as good conditions in actual practice.

Mr. Davidson: I will agree that $\frac{Wl}{8}$ is the best formula to use, because, as the Chairman remarked, we do not always know we are going to get the proper mixing and placing of concrete. I prefer to use $\frac{Wl}{8}$ for ordinary purposes.

I. F. Stern, M. W. S. E.: I have been trying to get an estimate or some sort of clear idea as to the actual angle of repose of the cement stored this way. I have heard tonight three different statements made in regard to it. First, Mr. Gibson stated that when cement is first put in the bin it takes practically a horizontal angle of repose. Then when the question of what is added to the horizontal pressure on the walls came up, it was stated that the pressure was 20 lb. per sq. ft., or an angle of repose of about 40°. Afterwards one of the other speakers, in mentioning failures, said, "Of course this cement will flow at an angle of about 10°." Now I am "all at sea" with regard to this, and I really would like to be set right. If we have an angle of repose of zero we should have a horizontal pressure of about 90 lb. per sq. ft. In earth weighing 100 lb. per sq. ft., where we have an angle of repose of one and one-half to one, we get about 30% of the vertical load, or horizontal pressure, corresponding to about 32 lb. Now, if we have a horizontal pressure of 20 lb., it will correspond to the angle of repose of 40°. Have any tests been made to show what this actual angle of repose is? That is one question.

Now a further question, or a further statement. I cannot see that there should have been any question regarding the bending down of these struts between the columns. There is that same condition far away from cement plants. The case often comes up in railroad work, where cylinders have to be put down in some depth of water, which height of water, rather, is reached only at certain times. It is necessary in such cases, to put struts in between the cylinders, as braces, but they are placed above the high-water mark, for if this is not done the freezing water forms ice near this high-water mark and as the water recedes the ice is likely to wreck the struts. So I can understand very well how the struts mentioned above can be wrecked, and I do not think it is at all remarkable.

But with regard to the other question, it seems to me that the pressure of 20 lb. per sq. ft. is a very small pressure horizontally, especially if we take into account the voids that are experienced in the cement on account of the expulsion of the air and then its sudden surging one way or the other. I would like to hear some explanation upon that subject.

Mr. Brunner: When the cement is first put into the stock house by the conveyor, it is, as has been explained in the paper, highly charged with air and the angle of repose is practically nothing. After it has settled down one can cut into it with a shovel and get a practically vertical wall, but if it is then disturbed in the slightest degree, it will slide out and run almost like water, and form an angle about 6° with the horizontal before it stops. I understand that the 40° angle of repose was found from experiment by figuring from the deflection of the beams which had held pressure from the cement on the inside of the bins. This may explain the reason for the different angles that have been mentioned in the discussion.

Mr. Stern: Then the 40° was not an observed angle at all, but was figured back from a 90 lb. vertical load per square foot with a 20 lb. horizontal load, and still there does not seem to be any unison between these two results, if we cannot get the cement to stand up at 40°, and it will flow out at the new angle of 6° set by the chairman,—the fourth angle which I have heard tonight. I confess that I am "all at sea" with regard to that. We can all design retaining walls if we know the conditions we have to meet. It seems to me that with a homogeneous substance, like cement, of a certain fineness we ought to know what we have. I would like to see some consistency and some logic in that.

Mr. Huey: The same question came up when we were talking about stock house No. 4. When we made that test we first made it with planks over the door and then took the same kind of a plank to see what load would make the same deflection, and arrived at our results that way. Unfortunately, however, the two planks were not the same strength, or something else was the matter with them, and the results were not very good. A test was made afterwards with the small I-beams and the results came out quite consistently, and as Mr. Carlson said, I believe, at 40° as the angle of repose, though the exact angle of repose when the cement is drawn from the bins I think is nearer 57° than it is 40°. I have been at the bins many times when we have drawn them out and the actual angle of repose has been nearly 60°. This gives a fifth number of degrees. I think, though, that there is something peculiar about it, because when we figure the angle of repose at 60° or 57°, it gives a certain pressure, and when we test it, it gives another angle of repose,—that is, about 40°; so the only thing we could do was to work from a safe standpoint, or 40°. Cement is a very peculiar material. I have seen it when it has been shoveled straight up and down, and then when somebody touched it, it would flow nearly like water. I have seen it flush out of a door 6 ft. high clear across the packing room 40 ft.

Mr. Davidson: It occurred to me, while Mr. Huey was speaking, whether or not measuring the deflection of a board or I-beam across a small opening would be a fair test on the pressure of cement. That would be a proper and perfect test if cement acted as a perfect liquid, but it does not. I doubt if such a test would indicate results of any value, on account of the arching effect of the material itself.

Mr. Huey: This test that we made was, as I remember, on about an 8 ft. span. We went inside of the bin and built up a framework so we had, I think, about 8 ft. as a span and an area of about 60 or 64 sq. ft., and arrived at our results that way. That was the only way that presented itself of doing anything practical.

Mr. Brunner: That means, in other words, as I understand it, that the doorway formed one side of the bin that you built up. Am I correct?

Mr. Huey: We went inside the bin and built a kind of a curbing in there, I should say a couple of feet deep, with a framework about 8 ft. square, so that one could get into the bin; we then sealed it up on the top so that the cement would not come through, and just made our dimension across the opening 8 ft., and the doorway was in between.

Mr. Brunner: Were those beams placed in the doorway or were they placed against the curbing you spoke of?

Mr. Huey: The beams were placed against the curbing. The doorway was entirely independent,—was just a means of entrance into the little chamber.

Mr. Davidson: The actual conditions of a test of this kind would be as follows: The moment that the boards deflect even 1/16 in., we can all readily see that there is an arching action in the cement itself, and I do not believe that it is a fair test. If it were possible to actually measure that pressure, I think you would find the pressure to be a good deal more than the 20 lb. assumed.

Mr. Curtis: I think there is a good deal of truth in Mr. Davidson's remarks; but I also think the several angles of the discussion are possibly due to the fact that the cement is never in the same state, as Mr. Gibson remarks. It starts off in a fluffy sort of substance, full of air which is gradually expelled. I suppose that air is being gradually expelled all the time, so perhaps no two experiments are tried under the same conditions. Would not that account for the multiplicity of angles of repose?

Mr. Stewart: It seems to me that Mr. Stern is getting at the real kernel of the matter now, and that is, with the experience that we have had, what shall we do in future structures of this kind? We are in the habit of figuring retaining walls according to certain principles based on the angle of repose, but cement is found to act differently from the usual materials and the only way we can arrive at the angle of repose is by measurement of pressures and then working backward for the equivalent angle of repose. If we have the pressures, what is the difference about the angle of repose?

A Member: You will have to wait to see if plant No. 6 falls down.

Mr. Carlson: In connection with this test we have been speaking of, I wish to say we took observations from the beginning and until we drew the cement out of the bin; that is, after it was in there in its loose state and after it was settled. I cannot recall all the pressures, but we started in as soon as we had cement in the bin and carried it straight through until the cement was settled in the bin. That gave us an average pressure, I think.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS.

Extra Meeting, May 17, 1911.

An extra meeting of the Society (No. 747), being a meeting of the Hydraulic, Sanitary, and Municipal Section, was held Wednesday evening, May 17th.

The meeting was called to order at 8:15 p. m. by L. K. Sherman, Chairman, with about 50 members and guests in attendance. The minutes of the preceding meeting of this Section were read and approved. There was no other business, so the Chairman introduced Prof. Gardner S. Williams, who addressed the meeting on "Measurement of Water, Means Available, and their Relative Accuracy."

The Secretary read a contribution from Mr. R. M. Hosea, M. W. S. E., of Pueblo, Colo., on apparatus to measure velocity of flow in a closed conduit; this was illustrated by lantern slides.

General discussion followed from Messrs. Mead, Alvord, Baker, and Pearse, with a closure from Prof. Williams.

On motion from Mr. Alvord, a vote of thanks was tendered Prof. Williams for his valuable address.

The meeting adjourned at 10 p. m.

Extra Meeting, May 24, 1911.

An extra meeting of the Society (No. 748), being a joint meeting of the Electrical Section W. S. E. and the Chicago Section A. I. E. E., was held Wednesday, May 24th.

The meeting was called to order at 8:15 p. m. with Mr. J. G. Wray presiding and about 70 members and guests in attendance.

The Secretary announced that there would be no joint meeting in June, as the convention of the A. I. E. E. would be in session in Chicago that week. Also that no joint meeting would be held during July and August, but that it is hoped to hold such a meeting the fourth Wednesday of September, announcement of which will be made later.

The Chairman then introduced Mr. S. G. McMeen, a member of this Society and of the A. I. E. E., who presented his paper "Notes on a Telephone System Recently Built in San Francisco and Its Neighborhood." This address was illustrated by a number of lantern slide views.

Discussion followed from the Chairman and Messrs. W. Lee Campbell, F. H. Reed, A. B. Smith, D. C. Tanner, E. H. Smythe, A. Scheible, and J. G. Wray with a closure from Mr. McMeen.

The meeting adjourned about 10:15 p. m.

Extra Meeting, May 31, 1911.

An extra meeting (No. 749), a Ladies' Night, was held Wednesday evening, May 31st.

The meeting was called to order at 8:30 p. m. and Mr. W. R. Patterson, M. W. S. E., was introduced, who gave an interesting account of a recent trip through the West Indies and across the Isthmus of Panama. This was very fully and beautifully illustrated with many stereopticon views taken by the speaker on this trip which included visits to many of the less known Lesser Antilles. After the conclusion of the address, about 9:45 p. m., refreshments were served. About 100 members and guests, including many ladies, were present.

Regular Meeting, June 7, 1911.

A regular meeting of the Society (No. 750) was held Wednesday evening, June 7th. The meeting was called to order at 8:15 p. m. with President Chamberlain presiding and about 40 members and guests present. The reading of the minutes of the preceding meetings was dispensed with by consent. The Secretary reported from the Board of Direction that applications for admission to the Society had been received from the following:

No. 56, F. Norwood Wilson, Chicago, transfer from Junior.
No. 57, Frank A. Berry, Chicago.
No. 58, Joseph L. Canby, Danville, Ill.
No. 59, S. A. Willmarth, Chicago, transfer from Junior.
No. 60, H. W. Clausen, Chicago, transfer from Junior.
No. 61, Frank G. Walter, Jr., Chicago, transfer from Junior.
No. 62, H. A. Tedman, Chicago, transfer from Junior.
No. 63, E. Robins Morgan, Chicago, transfer from Junior.
No. 64, H. S. Shimizu, Chicago.
No. 65, Henry J. Burt, Chicago.
No. 66, L. B. Hollingsworth, W. Lafayette, Ind.
No. 67, Perry Barker, Boston, Mass., transfer from Junior.
No. 68, Hymen E. Goldberg, Chicago.
No. 69, Ernest A. Clark, Chicago.
No. 70, Edward Gudeman, Chicago.
No. 71, George W. Brady, Chicago, transfer from Junior.

Also that the following had been elected into membership:

No. 6, Cesare Barbieri, Chicago, Member.
No. 23, Jas. W. Kern, Jr., New Orleans, La., Junior Member.
No. 28, Chester B. Lewis, Chicago, Associate Member.
No. 38, O. A. Tislow, W. Lafayette, Ind., Student Member.
No. 39, Wm. H. McGann, Chicago, Junior Member.
No. 42, Carl B. Williams, Chicago, Associate Member.
No. 43, Wm. F. Mann, Kokomo, Ind., Member.
No. 45, Jacob S. Spiker, Vincennes, Ind., Member.
No. 46, Frederick A. Smith, Chicago, Member.
No. 51, John N. J. Hilbert, Chicago, Associate Member.
No. 52, Ervin J. Bayer, Mt. Carmel, Ill., Junior Member.
No. 54, James W. Bradford, Chicago, Member.
No. 55, Frank L. Stone, Chicago, Member.

Mr. Victor Windett, M. W. S. E., was then introduced, who read abstracts from his paper on "Foundation and Sewer Work. Costs and Comments." Some stereopticon views were shown in illustration of the paper.

Discussion followed from the Chairman and Messrs. Grant, Saner, Davidson, Sherman, and the author.

The meeting adjourned about 9:40 p. m.

Extra Meeting, June 14, 1911.

The called meeting for June 14, 1911, in the interest of the Bridge and Structural Section, when a paper on Structural Steel Design was to have been presented by Mr. Albert Reichmann, M. W. S. E., had to be postponed on account of the unavoidable absence of Mr. Reichmann. No meeting was held.

Extra Meeting, June 21, 1911.

An extra meeting (No. 751), "Ladies' Night," was held Wednesday evening, June 21, 1911. The meeting was called to order at 8:30 p. m. by President Chamberlain with about 100 members and guests, including many ladies, in attendance. President Chamberlain introduced Mr. Wm. B. Leffingwell, traveler and lecturer, who gave a pleasant and interesting talk on the Yosemite Valley, including San Francisco and other parts of California. The address was illustrated with many beautiful stereopticon views. After the address refreshments were served and the assembly adjourned soon after 10 p. m. J. H. WARDER, Secretary.

BOOK REVIEWS

THE MANUFACTURE OF HYDRAULIC LIMES AND CEMENTS IN SOUTHERN FRANCE. (In German.) By Dr. Max Fiebelkorn. Tonindustrie-Zeitung, Berlin. 1911. Paper; 6½ by 9½ ins.

Under the foregoing title the author describes his experience and impressions during a short visit to the most important hydraulic lime and cement factories in the valley of the Rhone.

France, the foremost country in the world in the manufacture of hydraulic limes, owes this reputation to its enormous deposits of limestone carrying a high percentage of silica, which latter gives the calcined product hydraulic properties. There is an abundance of chalk or limestone to be found in England, Germany, and other countries, which has been discovered to be a valuable raw material for the manufacture of artificial hydraulic cements, but nowhere, except in France, does limestone occur in such vast amounts mixed by nature with the necessary ingredients to enable the manufacturer to transform it into a hydraulic cement of the highest grade by a simple process of calcination.

The hydraulic value of these limestones was established a long time before the Portland cement industry reached a high degree of development in Europe. This explains why even today probably as much hydraulic lime is used by French engineers as Portland cement, whereas in other countries Portland cement is used exclusively for the same class of work. Hydraulic lime has been used successfully in the most important harbor constructions in France, in the building of the Suez Canal, and in numerous other works of large proportions, without ever having shown the least sign of disintegration.

The process of manufacture is simple; it differs somewhat from the burning of ordinary lime and from the manufacture of Portland cement, inasmuch as it is more complicated than the former and less elaborate than the latter. Ordinary lime, which is used for common lime mortar, is merely calcined limestone of a high grade possessing no hydraulic properties. It is slaked or hydrated by the manufacturer or by the consumer on the premises and is then ready for use, and yields, mixed with sand, the ordinary lime mortar in which clay brick is commonly laid. The manufacture of hydraulic lime, on the other hand, is not completed upon calcining and slaking of the raw product. The slaking process has to be followed by a series of operations by which the hydrated material is separated into various grades of different hydraulic properties.

Consequently the machinery used in the manufacture of hydraulic limes consists mainly of kilns for calcining the limestone, hydrating chambers, sieves, and air-separators, for obtaining the different grades of hydrated limes, and of grinding-machinery in order to reduce to powder the hard part of the calcined product which did not disintegrate upon hydration and which latter answers in composition the product artificially obtained by the mixing of ground limestone and clay and subsequent calcination, namely Portland cement.

The publication is profusely illustrated with cuts showing the kilns and machinery employed in the manufacture as well as the location of a number of factories on the banks of the beautiful Rhone river. W. M.

THE PRINCIPLES OF SCIENTIFIC MANAGEMENT. By Frederick Winslow Taylor, M. E., Sc. D. Past President of The American Society of Mechanical Engineers. Harper & Brothers, New York, 1911. Cloth; 6 by 9 ins.; pp. 144. Price, $1.50.

During the last five years, in the eye of the public has been the great question of conservation of our natural resources. Behold, a prophet has arisen who tells us one of our great natural resources that badly needs conserving is our manual labor. There is no apparent danger of consuming the present crop before a new one can be grown; race suicide has not yet become popular among our fellow citizens who provide the bulk of our laborers and mechanics. What we want to conserve here is the efficiency of our labor, more than the supply of our laborers.

Among engineers and contractors there is no need of a revelation, through the mouth of a prophet, to bring a realization of the present inefficiency of labor. We have recognized it for years, and have also noted that this inefficiency was increasing year by year.

When the fight to secure the eight-hour day for mechanics was first being waged, we were told that a man could do as much in eight hours as he could in ten. This theory is too transparent a joke now for even trade union officials to promulgate. The unpleasant fact is that whatever men can do, entirely too large a percentage of mechanics and laborers today mean to do just as little work for a day's pay as will hold the job.

We recognize fully that unions are here and are here to stay. However much we deprecate the mistakes and shortcomings of union leaders, however much we hate the injustices and cruelties they perpetrate against the employer, the non-union man, and even the members of associated unions, no intelligent and fair-minded man can deny the great benefits which have come to labor, organized and unorganized, by way of the union.

What is needed today is to learn to handle men under the conditions that exist and which are going to persist, whether we like them or not, so as to get from those who toil with their hands the most for a given expenditure of time and effort.

There are two lines which promise results: the creation of a better attitude of mind in the worker, and the development of better ways of doing manual work, so that the same expenditure of effort will produce more result.

Mr. Taylor recognizes both of these elements, but is more interested in the second than the first, because there have been in recent years many efforts made to interest men to a greater degree in their work; there have been various systems of pay devised which would ensure some greater return to the rapid and skillful worker. But while these are good so far as they go, in Mr. Taylor's opinion they are all lacking in completeness,—they need something more added to produce the desired result,—and he believes the principles of scientific management properly applied and carried out meets the situation.

When we were boys, and railroads were considered blessings to a country and not simply enemies to be shot at, a good railroad locator—one who could pick out a route for a proposed road which would be economical in construction and operation—was a man specially endowed with a sixth sense, who could "smell" a way where apparently none existed. Today we have a suspicion that the best locator may be the man who understands best the science of railroad location, learned not intuitively but as we learn trigonometry or chemistry, and who applies that science by the way of the hard work of the topographical survey. While God made a few good locating engineers, our colleges can make many and better ones at that.

Mr. Taylor believes science applied to the handling of labor will work equally well, and why not? Why use all the trained skill on the design of a machine and none on the man who is to run it. Why spend time designing a machine to produce the desired result for the least weight, and with the least complexity, and spend none on the man who is to reproduce the machine from the drawings?

We have been neglecting one element of the composition and it is time we awakened to it.

The author's book is not an instruction book, it is rather inspirational. If you are an employer of men, after reading it you will not be able to go out and revolutionize your business. Mr. Taylor recognizes such transformations as he hopes for are not the result of days but of years. You will want and need to study further and dig deeper. All of the improvements necessary in any business cannot and need not be made at once. You will find here something which will suggest small changes and these will grow as you grow.

Mr. Taylor, to engineers, is a prophet in his own country but not one without honor. He is respected by all as a man who, if inspired by a theory, has first seen that theory worked out in practice, producing those commercial results and meeting the commercial tests to which everything of this kind must be subjected, and which they must measure up to, if they are to meet with favor. W. W. C.

RAILWAY SIGNALING. Wires and Cables. Line Construction. D. C. Relays. D. C. Track Circuits. Highway Crossing Signals. Vol. 1. By the School of Railway Signaling, Utica, N. Y., 1910. 1st ed. Leather back and corners; cloth sides. 6 by 9 ins.; pp. 222. Price, $5.00.

This volume, evidently a collection of texts used in the courses of the School of Railway Signaling, of Utica, N. Y., covers quite thoroughly the subjects of wires and cables, line construction, direct current relays, direct current track circuits, and highway crossing signals. The style throughout is simple and direct, and is well adapted to a work of this kind.

A considerable portion of the work is given to matters not perhaps directly needed in practical work, but a knowledge of which will undoubtedly increase the efficiency of the practical worker.

In the chapter on "Wires and Cables," for example, much space is given to such subjects as metals and their alloys, the processes of making wire, galvanizing and tinning. The greater part of the chapter is given, however, to such practical questions as the construction of cables, insulation, and specifications for rubber insulating compounds. In this, as in the other chapter, frequent reference is made to other texts of the school, treating of chemistry, materials, magnetism, and electricity.

The chapter on "Line Construction" treats in detail of aerial, underground, and submarine lines. The various types of poles, brackets, insulating devices and tools, as well as methods of bracing, crossing construction, and pole diagrams, and the numerous small details of construction are described and illustrated. The details of underground and submarine construction are treated in the same thorough manner.

For an understanding of the chapter relating to relays and track circuits, a knowledge of electricity and magnetism is necessary, and frequent reference is made to the texts relating to these subjects. Not only are the theoretical and constructional features discussed, but attention is given to such matters as track conditions as affecting the installation and maintenance of circuits.

The fullest treatment is given the subject of highway crossing signals. Owing to the numerous methods and devices used in this class of work this chapter is the longest in the book, the subject being treated rather exhaustively.

The book is designed for the use of students, but may well be used for reference by practicing engineers. In this connection attention might be called to one slight defect, the system of paging. This book is, in fact, five separate books bound together. The original paging of each book has been retained, and this leads to some inconvenience in using the index.

The work is well illustrated and contains numerous tables.

J. E. M.

PLUMBING AND HOUSEHOLD SANITATION, by J. Pickering Putnam. A course of lectures delivered before the plumbing school of the North End Union, Boston. Doubleday, Page & Co., New York, 1911. 718 pages, 5½ by 8 ins., cloth bound, more than 650 illustrations. Price net, $3.75.

This book sets forth the author's views, the result of more than 25 years study of the theory and practice in sanitary plumbing. The diction is simple and straightforward, to be readily comprehended by ordinary intelligence, with the object in view of meeting the practical needs of the general public. Sanitary engineers, however, as well as legislators, can profit by a perusal of this book. The purpose of this course of lectures is to show the best and simplest methods of securing healthy homes and how the best plumbing work may be had with safety and economy. The book, while illustrated profusely, is not a catalogue of fixtures and appliances, but the figures are introduced to show definitely the elements of construction which constitute good or bad fixtures. The simple item of wash basins, for instance, is shown in many forms and particularly of the waste and overflow, to explain what is desirable, or the contrary, for sanitary reasons. An interesting chapter is that on bacteria, in their relation to sanitary engineering. Another considers "Sewer Air" and its relation to good or ill health when present in our homes and places of business. Other chapters pertain to sewer ventilation and traps of various forms and construction, difficulties with traps, evaporation, siphonage, etc. Indeed the range of the treatment of the subject of plumbing is extensive and gives evidence of study and research. The book is dedicated to the Boston Society of Architects in recognition of their untiring and disinterested efforts in behalf of better building legislation.

WAR OR PEACE. A Present Day Duty and a Future Hope. By Hiram M. Chittenden, Brigadier-General, U. S. A., retired. Chicago, A. C. McClurg & Co. 1911. Cloth; 5¾ by 8½ ins.; pp. 273. Price, $1.00.

This book, written by an eminent military man, a West Point graduate (1884) belonging to the Corps of Engineers, who served in the Spanish-American War as Chief Engineer in the Fourth Army Corps, is very timely, in the opinion of the reviewer, considering the present wide-spread interest in the peace movement.

Chapter I, considers the "Mistaken Sanctions of War." Chapter II, relates to the "Condemnation of War." Chapter III, treats on "Armed Peace or Preparation for War." Chapter IV, takes up "The Rationale of Modern War." Chapter V, presents "The Present Duty," and Chapter VI, concludes with "The Future Hope."

In the first Chapter, Mistaken Sanctions of War, the author is illuminating in showing that it is a mistake to say that war has been a selective agency in the evolution of the race, for if long continued it causes deterioration in the physical vigor of the warring peoples. Again, war is not a force in material progress. At times war does supply a stimulus in scientific research and to invention, but on the other hand the development of high personal character is not necessarily dependent upon military service. In the next chapter, the author shows the moral damage of war,—the destruction of life and wealth; in other words, the economic waste of war. Again, the author shows the fallacy of many arguments advanced by the militarists in favor of armed peace or preparation for war, declaring that the results sought could be otherwise obtained without such a tremendous drain on the resources of the country, and that the piling up of armaments as is now the policy of England and Germany, makes for war instead of being a deterrent. He also states, "It is inconceivable that such a condition can foster any virtue of manhood or statehood which is not fostered more effectually in the conditions of peace, confidence, and friendship which prevails in the United States and Canada."

The author believes that "The Present Duty" is not for individual disarmament, but the continued preaching for peace and the awakening of public thought to the illusions which make war a possibility. But this thought cannot effect a great change in the condition of the world if followed by only one nation; disarmament needs to be practiced by the *whole world*, and not by one country only. For the United States, disarmament in advance of other great powers would be a perilous policy. From a consideration of the preparedness of Germany and other nations for such contingencies that may arise, the author thinks it is our duty to maintain an adequate naval force to protect American waters whether North or South, East or West. He further states, "It is only by a safe preponderance of naval strength that we are justified in maintaining so small an army." . . . . "The United States can make no greater mistake than to urge an abandonment of our military preparation in advance of other nations."

The concluding chapter of this interesting book is inspiring. "The Future Hope" is a federation of all nations of the earth, subject to the government of a central representative body, an amplification of The Hague Court of Arbitration, which would have the wisdom, power, and authority to settle all possible disputes between different nations, without conflict. This would also result in unification of laws, the restriction of commercial conflict in the way of tariffs on trade, and the unification of language. What progress of the world at large will follow, it is hard to adequately conceive, for the vast sums now expended in military matters, taking that in its broadest sense, would be available for other and more laudable purposes that would redound to the betterment of all mankind.

Geology of the New York City (Catskill) Aqueduct. Studies in applied geology covering problems encountered in explorations along the line of the Aqueduct from the Catskill Mountains to New York City. By Chas. P. Berkey.—Bul. 146 of the New York State Museum, John M. Clarke, Director. Issued by the University of the State of New York as an Education Department Bulletin No. 489—Albany, N. Y., February 15, 1911. pp. 283, 5¾ by 9 ins.; cloth; with many fine engravings from photographs and line drawings.

This is a very interesting book—to engineers, as giving one a very good idea of the magnitude of this work for an increase in the water-supply of our largest city, and to scientists as being a very illuminating exposition of many geologic problems and their solution.

The points considered are:

I. The Catskill Water Supply Project; the Problems encountered in the Project; Relative values of different sources of information; and General Geology of the region.

II. Geologic problems of the Aqueduct, which includes: The General position of the Aqueduct line; The Hudson River Canyon with the Geological conditions affecting the crossing of the same; the Geological Features involved in the selection of the site of the Ashokan Dam; character and quality of the blue-stone for structural purposes; the Rondout Valley, and the Wallkill Valley Sections; the Ancient Moodna Valley; Rock Conditions of Foundry Brook; Geology of Sprout Brook; Structure of Peekskill Creek and Croton Lake crossings; Geology of the Kensico dam site; stone of the Kensico quarries; the Bryn Mawr Siphon; Geological conditions affecting the location of the delivery conduits in New York City; special exploration zones; and in conclusion, the general question of post-glacial faultings.

It is seldom that construction works affords such admirable opportunities for the study of geological conditions as in this case. The great number of borings made along the line of the aqueduct for preliminary study of subsurface conditions gave certain data as to the condition, character, hardness, and soundness of the rock to be encountered in the construction of the aqueduct, and which information has been generally verified by subsequent explorations. These examinations show in many cases faulting of the rock strata accompanied with more or less rupturing of the rock that will introduce some difficulties in tunnel and shaft work, and perhaps permitting in some cases a great inflow of water. One of the interesting results is showing some deep gorges or valleys, probably of preglacial origin and subsequently filled with a great depth of glacial drift. The line of the tunnel work must be carried below these gorges to ensure stability.

The book having been written by a geologist, it makes a capital work for the use of those engaged in the study of that science and it is because of this educational value that it is issued by the University of New York.

June, 1911.

AN INTRODUCTION TO THERMODYNAMICS FOR ENGINEERING STUDENTS. By John Mills. Professor of Physics and Electrical Engineering, Colorado College. Ginn & Co., Boston, 1910. Cloth; 6 by 9 ins.; pp. 136, including index, with 64 diagrams in the text.

This is essentially a text-book and might be found rather hard reading, by those who have been for some years out of college, but it should be of considerable value in the class room.

Chapter I. Fundamental Concepts and Laws, comprises Work, Energy, Temperature, Thermal Units, Specific Heat, Latent Heat, Boyle's Law, Joule's Law, Absolute Temperature, Specific Heat of Gases, Adiabatic Transformation, First and Second Laws of Thermodynamics, Carnot Cycle, Entropy and Its Measurement, etc., etc.

Chapter II. Gases, is amplified into Graphical Representation of State for a Perfect Gas, Equations for Transformation, and Fundamental Heat Equations, for a Perfect Gas; Entropy Changes and Changes in Intrinsic Energy of a Gas, with Problems and Solutions, in Gases, etc.

Chapter III considers Water and Its Saturated Vapor, with Problems and Solutions, Saturated Water, Vapor, etc.

Chapter IV takes up Superheated Steam, considering Molecular States; Superheated Steam and its Specific Heat and Entropy, Intrinsic Energy, Superheating in Engineering Practice, and concludes with further Problems and Solutions in Superheated Steam.

Chapter V. Flow of Steam and Gases—also includes Problems and Solutions in the Flow of Fluids. The book concludes with four pages of Miscellaneous Problems, which are designed to test the student in his knowledge of the theory and principles laid down by the author, and form a valuable closure to this treatise on Thermodynamics.

TRACK FORMULAE AND TABLES. A Handbook of the Theory and Practice of Turnouts and Track Connections, with useful Tables, original and selected, for the use of Students and Engineers in the classroom, office and field. By Shelby Saufley Roberts, C. E. John Wiley & Sons, New York, 1910; flexible leather bound, 4x7 in., 514 pages. Price, $3.00.

The author states, "the purpose of the book is to present in a practical manner those track problems most frequently met in actual practice, supplemented by time-saving tables in connection therewith, and other tables of assistance in estimating." "The formulae are based on the actual properties of the frog and split switch. Most of them were worked out in the field and have therefore been tested in actual practice." "The author believes a strict adherence to the principles involved, if not to the formulae themselves, will result in better track work."

Chapter I treats of "Frogs and Split Switches"; it includes sundry problems which are worked out mathematically, and occupies some 30 pages.

Chapter II treats of "Turnouts Into Diverging Tracks," includes some 21 pages, and contains problems with diagrams and mathematical solutions.

Chapter III takes up "Crossovers," and Chapter IV "Connecting Tracks," which are similarly explained with diagrams, problems, and their solution. Other chapters follow, treating of "Wyes," "Parallel and Concentric Sidings," "Crossings," "Ladder Tracks" and "Vertical Curves," with problems and solutions for these several conditions.

Chapter XI consists of "Miscellaneous Formulae and Rules of the Thumb," which contains much of value to the railroad engineer. Many tables follow (over 300 pages), which are well arranged and convenient for reference. The makeup of the book, the paper, typography, illustrations and binding, are all excellent. It is a good book for the engineer to have.

LIBRARY NOTES.

The Library Committee desires to return their thanks for donations to the Library. Since the last publication of the list of such gifts, the following publications have been received:

MISCELLANEOUS GIFTS.

Doubleday Page & Co.:
  Plumbing and Household Sanitation. J. P. Putnam. Cloth.
School of Railway Signaling, Utica, N. Y.:
  Railway Signaling References, Vol. I. Cloth.
E. E. R. Tratman, M. W. S. E.:
  Proceedings, First Annual Meeting, American Association of Refrigeration, May, 1910. Pam.
New York Board of Estimate and Apportionment:
  Report of Col. Wm. R. Black and E. B. Phelps on Location of Sewer Outlets, New York Harbor. Pam.
California Railway Commission:
  Annual Reports, 1903, 1908, 1910. 2 Pams., 1 cloth.
Saskatchewan Department of Public Works:
  Annual Report, 1909-10. Pam.
  The Steam Boilers Act and Regulations for the Construction and Inspection of Boilers. Pam.
C. A. Schenck, Biltmore, N. C.:
  Forest Protection. Schenck. Pam.
  Forest Mensuration. Schenck. Pam.
  Forest Policy. Schenck. Pam.
  Biltmore Lectures on Sylviculture. Schenck. Pam.
L. K. Sherman, M. W. S. E.:
  Flow of Water in Open Channels and Sewers. Solution of $V=C\sqrt{RS}$. Values of C from Kutter's Formula. Folio. Dec., 1910.
Lyman E. Cooley, M. W. S. E.:
  Proceedings, Fifth Annual Convention of the Lakes to Gulf Deep Waterway Association. 1911. Pam.
  Lakes to the Gulf Deep Waterway Speech. L. E. Cooley. Pam.
Jones & Laughlin Steel Co.:
  List of Shapes, 1910. Leather.

EXCHANGES.

Institution of Electrical Engineers, London:
  Journal, April, 1911. Pam.
Institution of Mechanical Engineers, London:
  Proceedings, No. 3, 1910. Pam.
  List of Members, 1911. Pam.
Lawrence, Mass., Water Board:
  Annual Report, 1910. Pam.
Ohio Society of Mechanical, Electrical and Steam Engineers:
  Journal, Vol. III, No. 1. Pam.
Wood Preservers Association:
  Proceedings, Seventh Annual Meeting, 1911. Pam.
Colorado Scientific Society:
  Notes on Honduras. Proceedings, April, 1911. Pam.
Iowa Engineering Society:
  Proceedings, 23rd Annual Meeting, 1911. Pam.
Lowell, Mass., Water Board:
  Annual Report, 1910. Pam.
New York Public Service Commission, First District:
  Annual Report, 1909. 3 vols. Cloth.

June, 1911.

Iowa Department of Finance and Municipal Accounts:
    Third Annual Report, 1910. Cloth.
Wisconsin State Forester:
    Preliminary Report on Storage Reserviors, etc. C. B. Stewart. Pam.
Oklahoma Geological Survey:
    Bulletins, 2 and 3. Pams.
Illinois Society of Engineers and Surveyors:
    Proceedings, 1911. Pam.
Prof. U. S. Grant:
    Mining and Prospecting on Prince William Sound, 1909. Grant. Pam
    Structural Relations of the Wisconsin Zinc and Lead Deposits. Pam.
Indiana Sanitary and Water Supply Association:
    Proceedings, Fourth Annual Convention, 1911. Pam.
Ohio State Board of Health:
    Annual Report, 1909. Cloth.

GOVERNMENT PUBLICATIONS.

Smithsonian Institution:
    Classified List of Smithsonian Publications, May, 1910. Pam.
U. S. Geological Survey:
    Bulletins Nos. 438, 447, 453, 465. Pams.
    Water Supply & Irrigation Papers Nos. 257, 270. Pams.
    Professional Paper No. 72. Paper.
U. S. Commissioner of Education:
    Report, 1910, Part II. Cloth.
U. S. Lake Survey:
    Survey of Northern and Northwestern Lakes, with supplement. 2 pams.
U. S. Bureau of the Census:
    Bulletin, Agriculture, Wisconsin. Pam.
U. S. War Department:
    Report of Chief of Engineers, 1910. Cloth.
    Report of Secretary of War, Chief of Staff, etc. Cloth.
    Report of Various Departments of the Army. Cloth.
    Report of Philippine Commission. Cloth.
U. S. Department of Agriculture:
    Lawn Soils. Pam.
    School Gardens. Pam.
    Food Customs and Diet in American Homes. Pam.
    Bitumens and Their Essential Constituents for Road Construction and Maintenance. Pam.
U. S. Bureau of Mines:
    Technical Paper No. 1. The Sampling of Coal in the Mine. Pam.
    Technical Paper No. 2. The Escape of Gas from Coal. Pam.

ADDITIONS TO MEMBERSHIP.

Cesare Barbieri, Chicago	Member
E. J. Bayer, Mt. Carmel, Ill	Junior Member
James W. Bradford, Chicago	Member
J. N. J. Hilbert, Chicago	Associate Member
J. W. Kern, Jr., New Orleans, La	Junior Member
Chester B. Lewis, Chicago	Associate Member
Wm. F. Mann, Kokomo, Ind	Member
William H. McGann, Chicago	Junior Member
F. A. Smith, Chicago	Member
J. S. Spiker, Vincennes, Ind	Member
Frank L. Stone, Chicago	Member
Oswald A. Tislow, Petersburg, Ind	Student Member
Carl B. Williams, Chicago	Associate Member

Journal of the
Western Society of Engineers

VOL. XVI SEPTEMBER, 1911 No. 7

THE SEWERAGE SYSTEM OF CHICAGO

C. D. Hill, M. W. S. E.

Presented January 30, 1911.

A matter of the greatest importance to the public welfare is the maintenance of sewers and drains and the proper disposal of the sewage of the community. Too often this is neglected for the reason that it is not brought to the attention of the public. A pile of filth on the surface of the streets calls for prompt action, while a greater amount lodged in a sewer where it is causing much more harm is unnoticed. However, if this matter is neglected too long the evils become so pronounced and unpleasant that the community is stirred to action.

The seriousness of this problem was becoming very acute in Chicago in 1855 when the first "Board of Sewerage Commissioners" was organized under an act of the State Legislature. This Board selected Mr. E. S. Chesbrough as its Chief Engineer and directed him to proceed to prepare comprehensive plans and estimates for a system of sewers.

Before taking up the work done by Mr. Chesbrough it might be well to consider the topographical features and natural conditions of Chicago at that time.

The site of Chicago in 1855 was a low, flat, marshy prairie lying north, south, and west of the river and its two branches. At that time the elevation of the streets in what we now call the loop district was from 6 ft. to 10 ft. above the lake level; the present elevation of these streets is from 13 to 14 ft. The condition at that time was similar to that of the Calumet region today.

If we go beyond the flat plain upon which the central portion of Chicago was built, we find clay bluffs rising along the shore of the lake, extending north from Wilmette. West of these bluffs is the Skokie Marsh and the head waters of the north branch of the Chicago River. Further west is a high ridge separating the Chicago from the DesPlaines River. This ridge, which forms the divide between the great lakes and the Mississippi basin, extends south to about the line of North Avenue. From this point to Beverly Hills (at 87th Street and Western Avenue) is a flat prairie, the lowest portion of which (at Ogden ditch) is about 10 ft above the level of the lake. This Ogden ditch is along a natural waterway forming a connection between the Chicago and the DesPlaines rivers, and in times of high water it was possible for small boats to pass from the waters of the lakes to the waters of the Mississippi.

The Blue Island ridge extends south from Beverly Hills to the Calumet River, a distance of about six miles. Here is another natural depression which connects the Calumet with the DesPlaines River.

The Calumet basin extends over the northern portion of the State of Indiana, and at the present time is a very important element in the sewerage problem of Chicago. This will be considered more in detail later.

When Mr. Chesbrough was appointed Chief Engineer of the Sewerage Commission he set to work to obtain all information possible. For this purpose he obtained many documents and reports from other cities, especially from England. At that time there was a commission at work in London planning a modern system of sewers that was intended to replace some of the archaic sewers of that city and to unite them into a harmonious whole. The engineers in charge of that work were able men, and many of the conditions there were similar to those of Chicago. It was fortunate for us that Mr. Chesbrough appreciated the wisdom of those men and applied some of their theories and methods to the problem here, and was not influenced by more

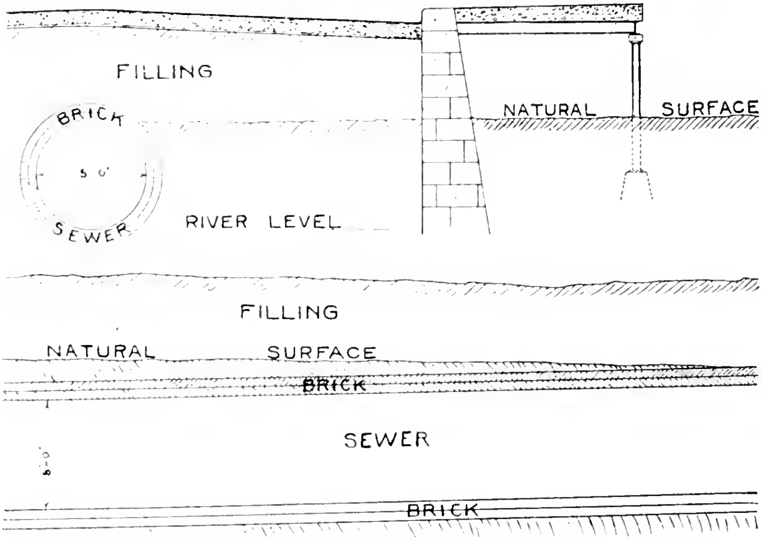

Fig. 2.—Typical Chicago Sewer.

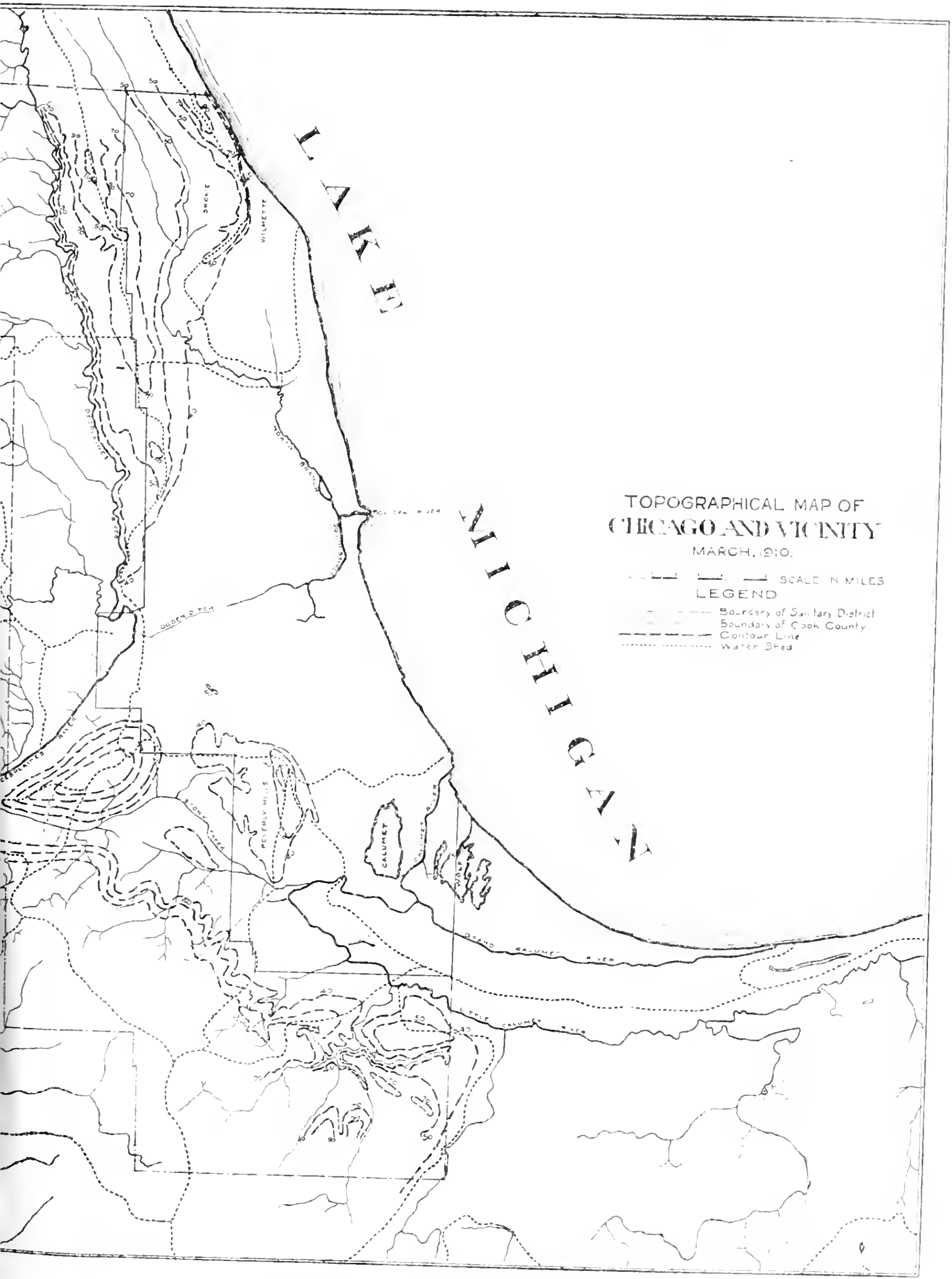

Fig. 1.—Topography of Chicago and Vicinity.

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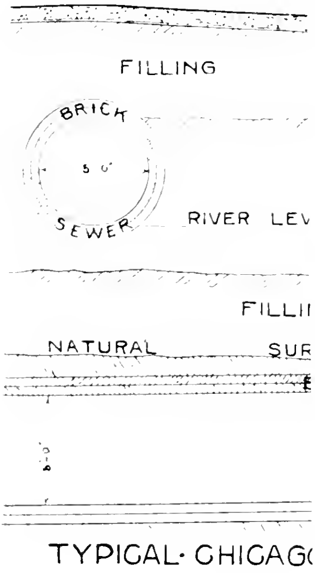

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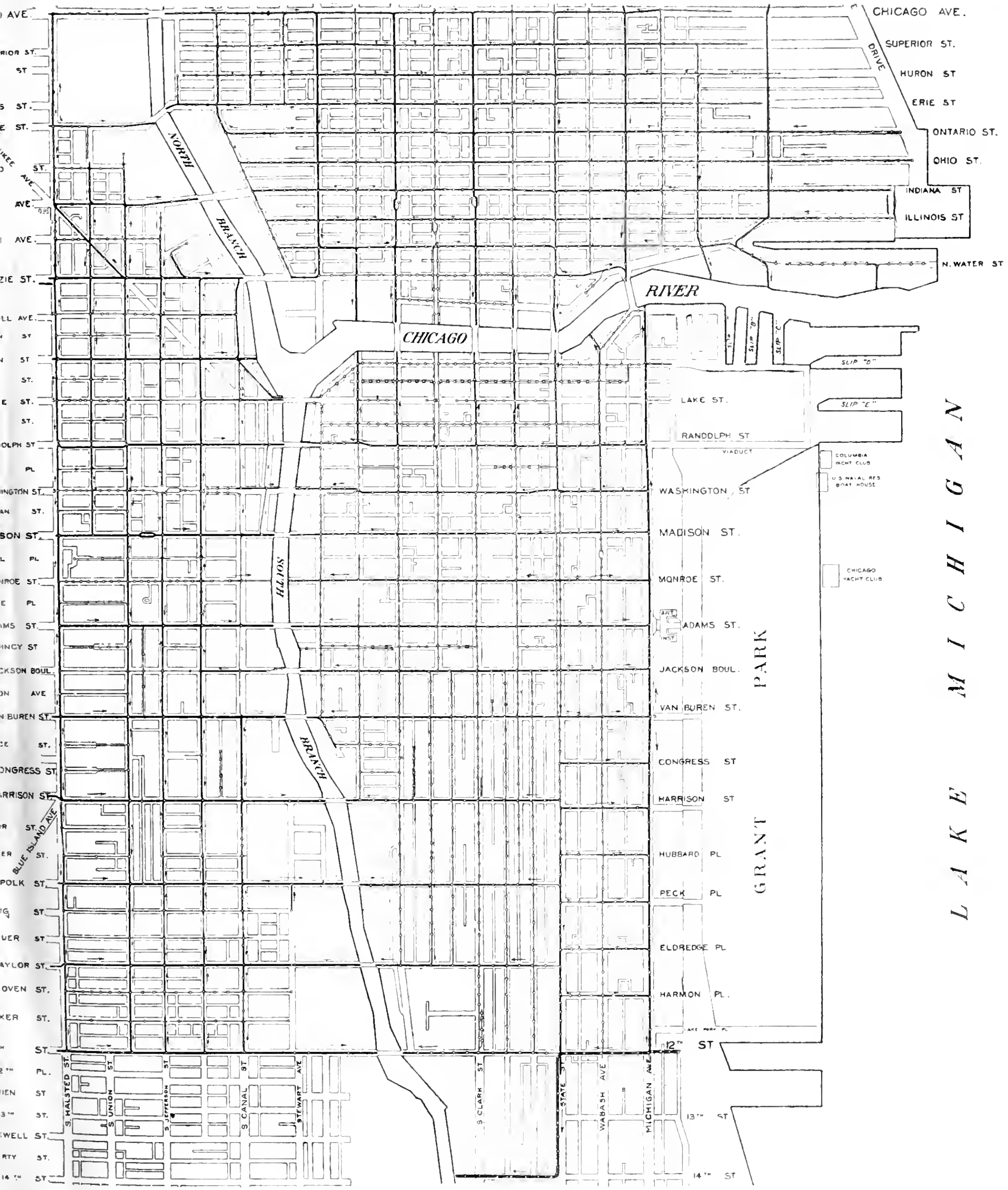

Fig. 3.—Sewer System of Central Chicago.

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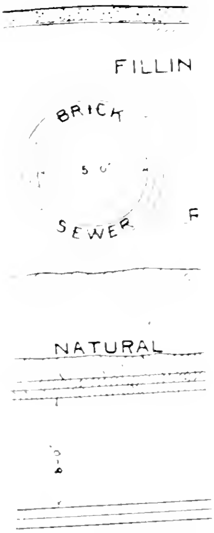

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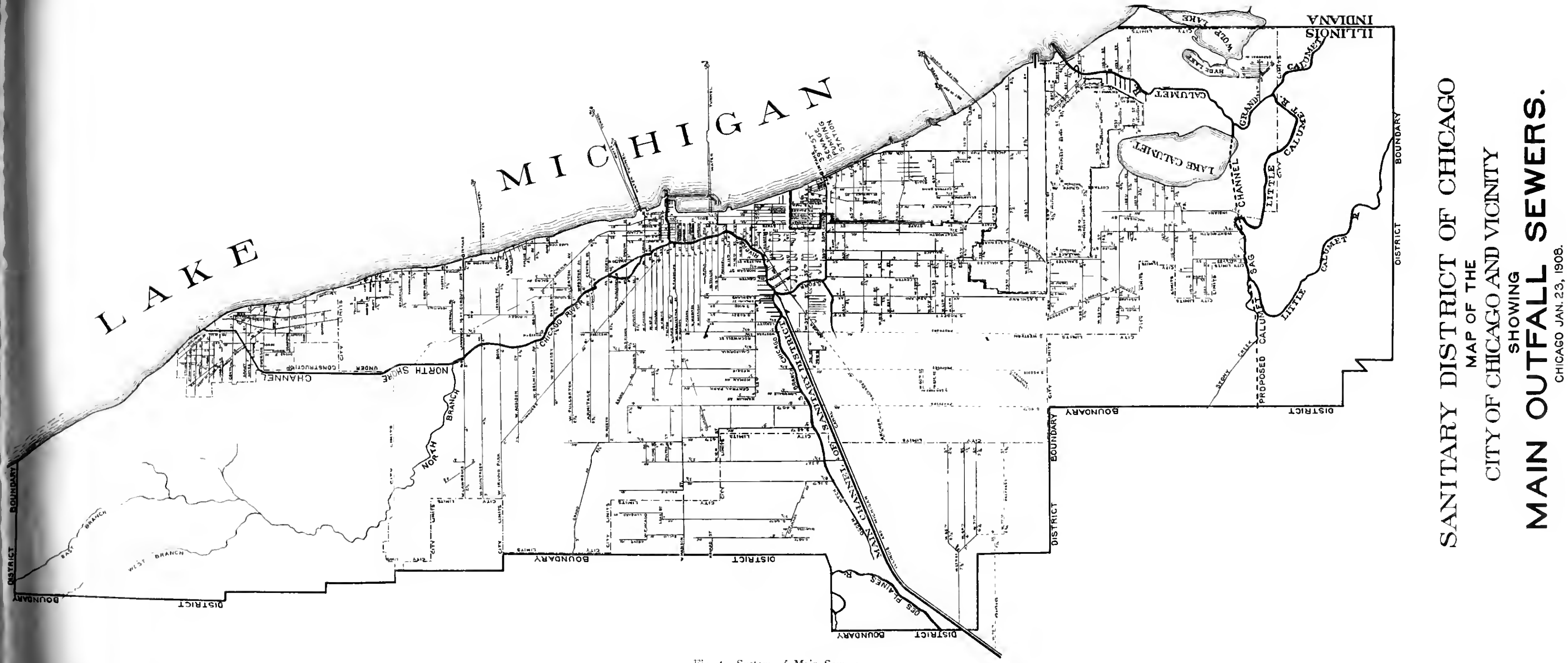

Fig. 4.—System of Main Sewers.

radical theories in vogue elsewhere. The fact that the first sewers built in Chicago by Mr. Chesbrough are in use fifty years later, giving fairly good service, is sufficient evidence of his wisdom.

The sewerage problem of Chicago at that date was both simple and difficult. It was simple in that it was only necessary to build sewers in parallel streets with outlets at the river. It was difficult for the reason that the ground was so low that the tops of the sewers of sufficient size would be at the surface of the ground. This would necessitate filling the streets to protect the sewer. There was not sufficient rise in the ground away from the river to enable the sewers to have a gradient and consequent velocity of flow that would make them self-cleansing. Mr. Chesbrough also considered an alternate plan of deep sewers with sufficient gradients which would have involved one or more pumping stations operated at a perpetual cost of a considerable amount. He recognized the fact that shallow gravity sewers would not adequately drain cellars, and stated that if sewers were so designed there was nothing to prevent property owners from building deeper cellars, below the level of the sewers, and called attention to the fact that two-story cellars were then in existence in New York and Boston.

Mr. Chesbrough recommended the construction of the shallow gravity sewers in each of the streets of the South Division draining from State Street to the river on the west, and from Washington Street to the river on the north, the portions east of State Street draining into a main sewer in Michigan Avenue, with one outlet at the river and another at 12th Street and the lake. These sewers were all built substantially as first designed.

For the north division he proposed three main sewers, in Rush Street, Clark Street, and Franklin Street. These were built and afterwards were supplemented by others in intermediate streets.

For the West Side he proposed a large main sewer in every third street with the prediction that ultimately it would be necessary to lay large main sewers in each of the intervening east and west streets.

Before the work was commenced the plans were changed to provide for a main sewer in every second street and the sewers were so built.

In his report he stated that these sewers would probably take care of a rainfall at the rate of an inch an hour, and experience has shown that even today a rainfall that does not exceed an inch an hour will barely fill the sewers. Of course, an inch an hour is not sufficient for a small surface that is well built over.

Mr. Chesbrough had no difficulty in deciding in favor of shallow sewers against low-level sewers with resultant pumping stations. Today the city is continuing that policy in a part of the Calumet district, and is building low-level sewers in other parts. It is quite probable the city will replace some of the shallow sewers with low-level sewers, but that policy has not been definitely adopted.

After work had been commenced on the construction of sewers, Mr. Chesbrough went abroad and studied the work being done in the various cities of Europe, and on his return in 1858 submitted a very interesting report, which may be found in the Crerar Library. It is of interest to note that at that time the City of Berlin had no sewers; that no city had a well-organized system of sewerage, and that Chicago has the distinction of being the first great city to have a comprehensive system of sewerage that was well designed from the beginning.

The sewerage system was developed and extended over the whole area of Chicago as it existed prior to the extensive annexations of 1889. It will be noted that the main sewers are farther apart in certain sections (as along 22nd Street west of Western Avenue) than they are in the center of the city. When those sewers were designed, Mr. Chesbrough's successors had little faith that this outlying, almost suburban, territory would become as densely populated as the territory near the heart of the city. These sewers have now become too small and the condition must be relieved by the construction of new large sewers. Similar conditions exist along West Armitage Avenue, in the north division south of Fullerton Avenue, and in the south division north of 39th Street.

In 1889 about three-fourths of the present area of Chicago was added to the city. For the greater part this comprised vacant tracts of land with scattered settlements. There were numerous small sewers designed for the use of small, sparsely settled villages, and in many cases the size of the sewer was determined, not by the size of the district to be drained or the amount of rainfall, but by the amount of money that could be raised by a special assessment levied on the land. The rapid growth of population and the corresponding increase in the amount of roofs and pavements have made these sewers entirely inadequate—and in some instances relief sewers have been built, as in Hyde Park and a portion of Lake View.

The old village of Lake View was bounded on the west by Western Avenue and could get an outlet to the river only at the southwest corner. The Ravenswood district was sewered by a main sewer in Robey Street, extending south to Belmont Avenue, west to Western Avenue, and south to the river. The sub-main sewers in Lawrence Avenue, Montrose Avenue, Irving Park Avenue, and Addison Avenue, were fairly large, but the sewer in Robey Street was intentionally designed with a smaller capacity with the expectation that ultimately one or more outlets would be built to the river. This has recently been done, the sewers being built in Addison Street and in Montrose Avenue, the latter discharging into a 6 ft. sewer previously built in Montrose Avenue from Western Avenue to the river. At the time these relief sewers were built, connections were made between the system of sewers and the Lawrence Avenue conduit at Robey Street and at Western Avenue.

The city has prepared a plan for a proposed system of sewers that will relieve the congested sewers in the territory west of Western Avenue and south of Madison Street. These sewers will discharge into the West Fork of the South Branch, and the sewage will be carried into the Main Channel of the Sanitary District. It will be necessary to continue planning and building relief sewers all over the city. Even the sewers recently built in the outlying portions of the city will in time become inadequate when the population becomes more dense.

At this point it may be proper to state that although it has been necessary to replace a few of the sewers laid by the village authorities before annexation, because of the improper construction, there have been no sewers laid by the City of Chicago that have been replaced for that reason, and there have been very few instances where it has been necessary to make repairs on account of poor workmanship or material. Nor have we been able in fifty years to improve on the high standard of workmanship established in the beginning by Mr. Chesbrough.

In the beginning Mr. Chesbrough recognized the fact that the sewage discharged into the river would produce a condition that would become intolerable. He suggested the construction of intercepting sewers that would empty into the lake, preferably at a point south of the river. He also suggested a canal to connect the lake with the river at a point about 16th Street and another similar canal on the North Side. He intended that water should be forced through these canals from the lake to the river. He also considered pumping the water of the South Branch into the Illinois and Michigan Canal.

This last suggestion was carried out and a pumping station was established at Bridgeport which forced the water from the river into the canal. This proved to be inadequate, and in 1865 work was commenced on the deepening of the canal so as to obtain a steady flow from the lake. When this was completed a few years later it was thought that the problem had been successfully solved, but in less than five years thereafter a movement was started to increase the flow by the establishment of another pumping station.

This pumping station was completed in 1883 and continued in operation until the opening of the Main Drainage Canal of the Sanitary District in 1900. The capacity of the pumping station was about 50,000 cu. ft. per minute and its effect was to prevent flow from the river to the lake except in times of considerable rainfall; but there was never sufficient flow from the lake to dilute the sewage in the river to a perceptible degree.

Another suggestion of Mr. Chesbrough was carried out by the construction of the Fullerton Avenue conduit from the river to the lake. This was completed about 1870. At that time Fullerton Avenue was the northern limit of the city. A pumping station with a capacity of about 15,000 cu. ft. per minute was built at the river end of the conduit, and the machinery was so arranged that water could be forced in either direction. It was found that the best results, so far as the purification of the river was concerned, were obtained by forcing the water from the river to the lake, thereby producing an inflow of lake water at the mouth of the river. This conduit has continued in operation to the present time, but since the opening of the Main Drainage Channel of the Sanitary District the flow has been maintained from the lake to the river. Since the opening of the Lawrence Avenue conduit it has been suggested that the operation of the Fullerton Avenue pumping station should be abandoned. In my opinion this would be a mistake, as a number of sewers discharge into this conduit and it is available as an outlet for relief sewers which are needed in that portion of the city. Furthermore the city is receiving a considerable income from the use of water for condensing purposes and this income may possibly be increased sufficiently to pay for the cost of operating the pumping station.

The history of the organization of the Sanitary District of Chicago and the construction of the main drainage works is so recent and has been told so many times that it is not necessary to repeat it in detail. Briefly stated, the great flood of 1885 caused the DesPlaines River to overflow through the Ogden ditch into the Chicago River in great volume, sweeping all the accumulated filth of the river into the lake and carrying it to the water intake crib off Chicago Avenue. In consequence of this a Pure Water Commission was appointed, and Mr. Rudolph Hering was engaged as a sanitary expert to recommend some measure of protection. A thorough study was made of the problem and it was decided to construct a canal from the Chicago River to the DesPlaines River that would be sufficient to take the greatest flood water of the Chicago River, and to make other provisions that would prevent the DesPlaines River from overflowing into the Chicago River. It was decided that the capacity of the canal should be ultimately 10,000 cu. ft. per second, which Mr. Hering estimated would be sufficient to dilute the sewage of 3,000,000 people to such an extent as to render it inoffensive. The main channel has been constructed of full capacity in the rock sections, and it will be easy to enlarge it in the earth sections. As a matter of fact the channel through the rock section has a capacity of 14,000 cu. ft. per second. This increase in capacity is due partly to the fact that the sides of the channel were cut quite smoothly by a newly-invented channeling machine, and partly to the fact that the engineers were over-conservative in their calculations of the velocity of flow to be expected in such a channel. In January, 1900, the canal was opened and water flowed freely from the lake to the Gulf.

While the work of construction of the channel was actually in progress, the City of Chicago continued to build sewers emptying into the lake, especially at 70th Street and 73rd Street, very near to the Hyde Park water intake, and plans were prepared for another system of sewers that would empty into the lake at 83rd Street.

In 1896 Mayor Swift put a stop to such operations and appointed a commission of engineers to prepare plans for a system of intercepting sewers that should divert the sewage then flowing into the lake and cause it to discharge into the river where it would subsequently flow into the main channel of the Sanitary District. Those plans were prepared and were afterwards modified by an agreement between the City of Chicago and the Sanitary District, whereby it was provided that the conduits in 39th Street and in Lawrence Avenue should be made large enough to carry, in addition to the sewage, a considerable amount of water from the lake to the river for the purpose of flushing the two branches of the river. Those two systems of intercepting sewers, with their respective pumping stations, have been completed and have recently been put in operation. The south system intercepts all sewers that formerly emptied into the lake from 35th Street to 73rd Street. The sewage is raised by pumps which discharge into the 20-ft. conduit in 39th Street at the lake. At the same pumping station there are two large screw pumps that are capable of forcing 2,000 cu. ft. per second of lake water through the conduit, thereby flushing out the Stock Yards slip of the South Branch.

The northern system intercepts all sewers along the lake from the northern limits of the city to Lincoln Park, and a pumping station at Lawrence Avenue east of Evanston Avenue operates in a similar manner to that at 39th Street.

A part of the intercepting sewer system that is apt to be overlooked is the sewer extending from the lake at 12th Street west by way of State Street to the river at 14th Street, and a similar sewer extending from the lake at 22nd Street to the river at 21st Street. These two sewers were built in 1898, and diverted from the lake the sewage from a population of about 100,000. Within six months after these sewers were in operation there was a marked decrease in the typhoid death rate of the city.

After the opening of the Main Drainage Channel there was a marked improvement in the quality of the water furnished from the intake near the mouth of the river, but there were indications of contamination at the Lake View intake due to sewage from municipalities north of Chicago, and also at the Hyde Park intake, which is about four miles from the mouth of the Calumet River.

As the result of considerable agitation, the Sanitary District was extended on the north to the county line, so as to include Glencoe, Winnetka, and Wilmette, and on the south it was extended to include the remainder of the City of Chicago and the villages of Dolton, Harvey, and West Hammond.

The North Shore Channel, from the Chicago River at Lawrence Avenue to the lake at Wilmette, is now practically completed and a pumping station has been established at its north end near the lake for the purpose of forcing lake water through the channel into the North Branch of the Chicago River and thence into the Main Drainage Channel. It is expected that a system of intercepting sewers will be built that will divert all the sewage from those northern municipalities to the North Shore Channel.

The Calumet problem is too large and too complicated to be discussed in a few moments. It deserves more consideration than can be given to it alone in an evening's discussion. At the present time it is the most live and important problem connected with the disposal of our sewage. The proper solution of the problem involves action by municipal and state authorities in both Illinois and Indiana, and Federal action as well. The greatest danger to Chicago's water supply is from the pollution coming from the sewage of the Calumet district. The water supply of northern Indiana is already grossly polluted. Aside from the difficulty of obtaining the necessary governmental action of so many political bodies, the engineering problems involved are more difficult than any heretofore solved in connection with our sewerage problems.

The Calumet River drains an area of about 800 square miles, of which about one-half is in Illinois and one-half in Indiana. During extreme dry periods there is scarcely any flow (less than 500 cu. ft. per second) and at other times more than 10,000 cu. ft. per second has been observed. This district has a population of about 200,000, which will soon be doubled and the doubling operation will be repeated more than once. About one-half of the present population is in Chicago. The sewage of these people who are in Chicago is discharged directly into the Calumet River. The sewage of the Indiana municipalities is discharged either into the lake or the river. In addition there is a vast amount of filth from industrial establishments, particularly from the stock yards at Hammond, that is discharged into the river, and from the glucose works at Robey, that is dis-

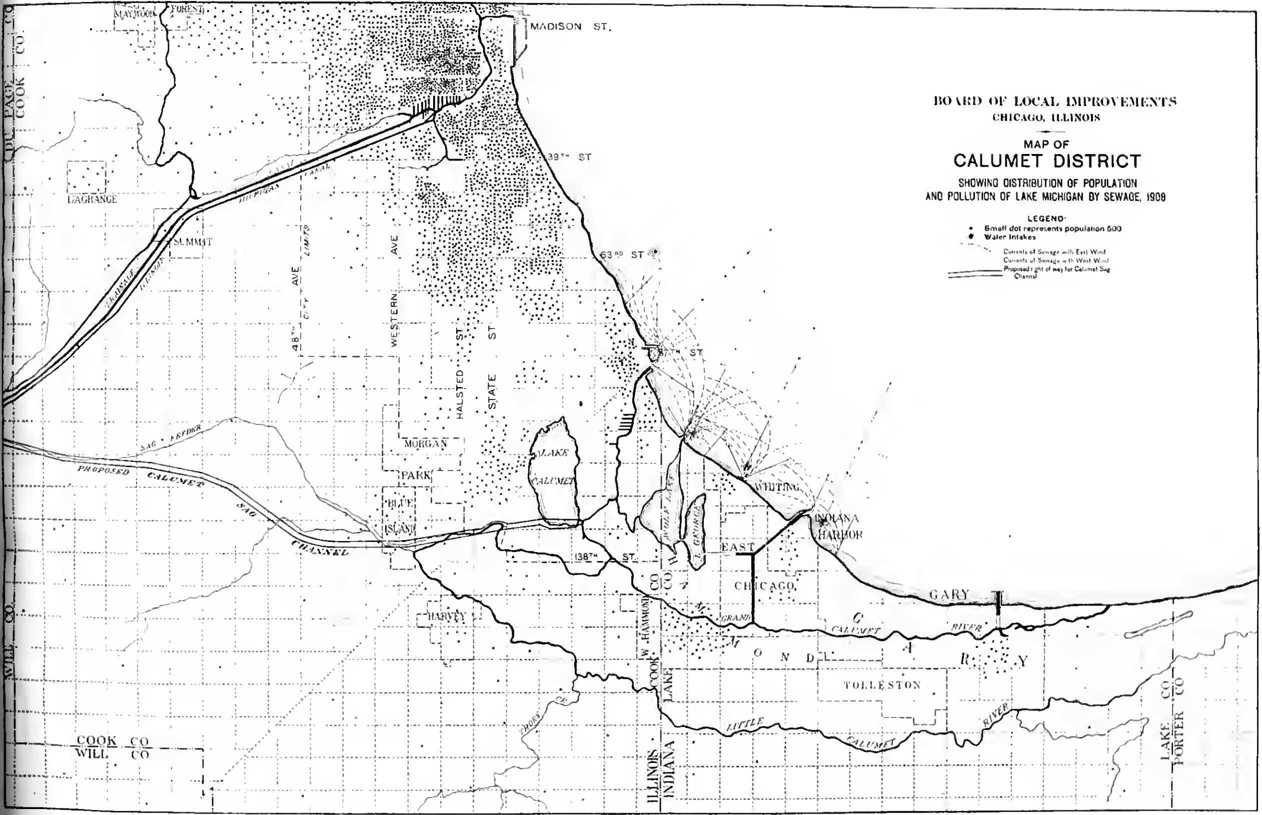

Fig. 5.—The Calumet Region.

charged into the lake. The water of the lake at the latter point is more polluted than at any other point, not excepting the mouth of the Calumet River.

During the summer of 1908 Messrs. Barnard and Brewster, chemists of the State Board of Health of Indiana, spent six weeks making a most thorough survey of the water of the southern end of Lake Michigan. Samples of water were taken daily from fifty points in the lake ranging from East Chicago to the Hyde Park intake, extending for a distance of five miles into the lake. Analyses of the water, as well as visual observations of well-defined currents of sewage demonstrated beyond possibility of dispute that at times the contamination extends five miles from the outlets of the sewers and the river. The direction of the flow depends upon the wind and the resultant currents in the lake. Any one of the intakes is liable to be contaminated by any one of the sources of pollution. The direction and extent of some of these currents as observed is indicated on the map (Fig. 5). At the Hyde Park intake the pollution was very marked on at least two occasions and the average was more than should be permitted for any water for domestic use.

Without going into details or giving reasons for the opinion expressed, the apparent solution for Chicago is the construction of a canal from the Calumet River to the Main Channel of the Sanitary District at the Sag, the construction of controlling works that will permit as large a flow as possible from the river to the canal and that will exclude excessive flood water, and the construction of intercepting sewers that will deliver all of the sewage from Chicago to the canal at a point west of the controlling works. The work of constructing this canal has been delayed by the failure of the Sanitary District officials to receive from the Federal Government the necessary permit, but it is now being actively pushed and actual excavation will be commenced this year.

It has been suggested that the authorities of the State of Indiana authorize the formation of a Sanitary District similar to that of Chicago. The officials of such a district should provide a supply of pure water for its inhabitants and provide for the proper disposal of its sewage. The simplest method of sewage disposal would be to drain into the Calumet River and then into the proposed Sag canal. Chicago will never consent to this unless the sewage is first purified, or at least partially so, for the reason that there will not be sufficient water in the canal to dilute the sewage so as to render it inoffensive. There have been several attempts to have constructed so-called drainage ditches in Indiana from the Little Calumet River to the lake. If this is done it will diminish the difficulty of taking care of the storm water in Illinois but it will greatly increase the pollution of the lake near Gary.

September, 1911

It has been proposed that the Calumet problem should be solved by means of sewage purification works and not by means of the Sag canal. There are good reasons why it is not advisable to rely on such methods alone. While a great deal can be done and has been done in the way of sewage purification, the results are not as satisfactory as could be wished. Besides that, there are many sources of pollution in the Calumet district and at the best a good deal of filth would find its way into the river and into the lake. If a canal of comparatively small size were built, 90% of this filth would be diverted from the lake.

When the Sanitary District of Chicago was formed, it was expected that the flow of 10,000 cu. ft. per second would be sufficient to dilute the sewage of 3,000,000 people. Before the officials of the Sanitary District complete their present projects, we will have that population within the limits of the District and once more we will be face to face with the old problem of purifying a filthy stream. It may be that the Federal Government will permit us to increase the flow to 14,000 cu. ft. per second, which will give a respite until 1,200,000 more people are added to the population. Eventually we will be obliged to do something else. If we can combine dilution with some other form of purification, the result will be more satisfactory than either method alone. If we can adopt some cheap and rapid method of treatment that will remove 50% of the organic matter from the sewage, the water from the lake will be sufficient for twice the population. In addition to this there is a growing

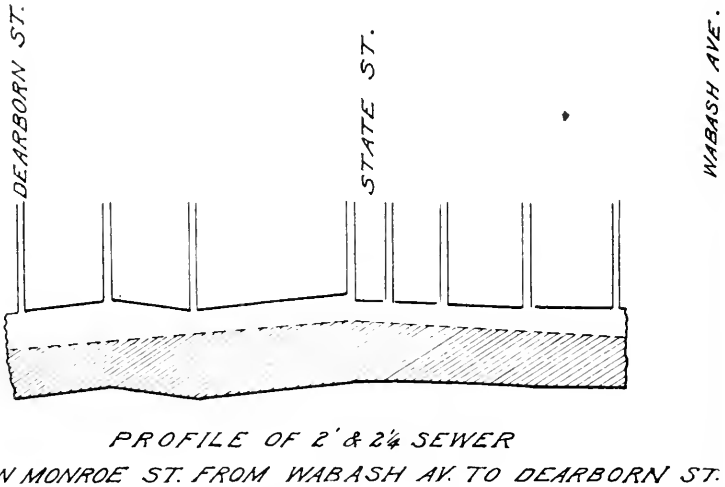

Fig. 6.—Clogged Sewer.

sentiment, that will be followed by legislation, against discharging raw sewage into any body of water.

The officials of the Sanitary District have recognized this condition and have established an experimental station at the pumping station at 39th Street and the lake, where an extensive series of experiments are being made with various forms of filters. These experiments will extend over a year or more and should be followed by actual installations on a large scale.

For the immediate future the most important work is the reconstruction of the sewers in the *Loop District.* This work cannot be designed intelligently until some definite plan is adopted for a system of subways or until it be definitely decided that no subways are to be built.

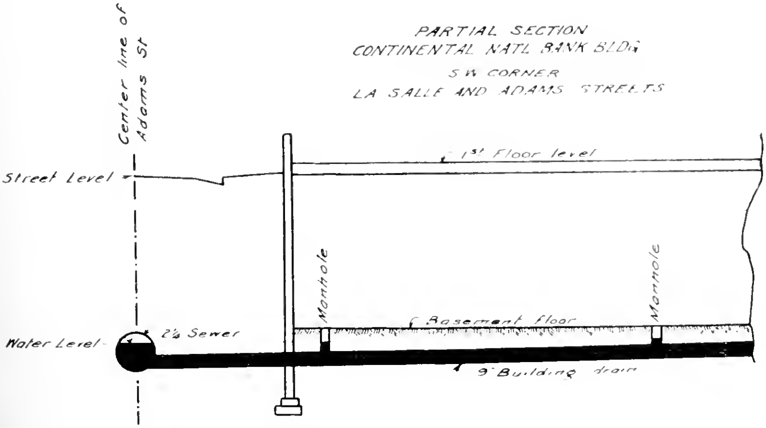

Fig. 7.—Clogged Sewer and House Drain.

This matter has been the subject of a special report* which has been prepared by direction of the City Council of the City of Chicago. This report shows that the sewers in the downtown district are insufficient in size; that many of them have been badly damaged by the construction of buildings and other structures; that they are not self-cleansing; that it is very difficult to clean them; and that as a general rule they are half filled with dirt and water even in dry weather. This report shows that the entire sewer system in the downtown district should be condemned and replaced with an entirely new system that will be up-to-date and that will take care of all possible developments of the district.

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*Note.—This report was published in the Council Proceedings of the City Council March 27th, and is re-printed as an appendix in this issue of the Journal.

Discussion.

A Member: I would ask Mr. Hill if some of the sewers downtown in Chicago, which he has shown were exceptionally bad, or whether they were fairly typical of all the sewers downtown? Are we to understand that all the sewers in the downtown district of Chicago are more or less sunken through building operations and filled with water ordinarily?

Mr. Hill: I am unable to say whether the sewers shown are exactly typical or not. That is, we have many complaints from various parts of the downtown district, and on investigating some of them we have found conditions as indicated in the illustrations. These illustrations are the only ones I could get on short notice. It is possible that many sewers are not as bad as those shown, although I cannot say from my own personal knowledge. I fear that the greater part of the tile-pipe sewers are in bad condition, but perhaps the brick sewers are better, as a rule, than the ones on Polk Street (See Fig. 8). I do not know any reason why the Monroe Street sewer should not be practically typical. Since the drawings of these illustrations were made we have investigated the sewer at Eldridge Court and Michigan Avenue, and that seems to be in even worse condition in the way of settlement than any of the others. The sewer in Eldridge Court west of Michigan Avenue is practically stopped up, due, I think, to building operations. A large building at the corner has caused the sewer to settle. A sewer in Randolph Street, at the Randolph tunnel, is practically out of commission for the same reason. You may have noticed in the streets in recent years that the whole street has settled a half foot or so. Whether the settlement has continued as far as the sewer or not, we do not know. We do know that the Adams Street sewer, from Michigan Avenue west, is almost worthless. There is trouble there continually from those old buildings. So that, in a way, the illustrations shown are typical, and I have no hesitation in saying that the whole sewerage system should be condemned without exception.

APPENDIX.

REPORT ON THE SEWER SYSTEM IN THE CENTRAL PART OF CHICAGO.

The City Council of the City of Chicago on January 24, 1910, passed a resolution directing the Board of Local Improvements to investigate fully the needs in the matter of the sewers of the district bounded by the River, the Lake, and Twelfth street, and to make report thereof to the Council.

This matter has been under consideration for many months, but it has been impossible to make a definite report for the reason that the solution of the problem depends upon the final plans for a system of subways to be built in the streets in the said district.

Description of Existing Sewer System.—This district is sewered by main sewers in all of the east and west streets from Randolph street south.

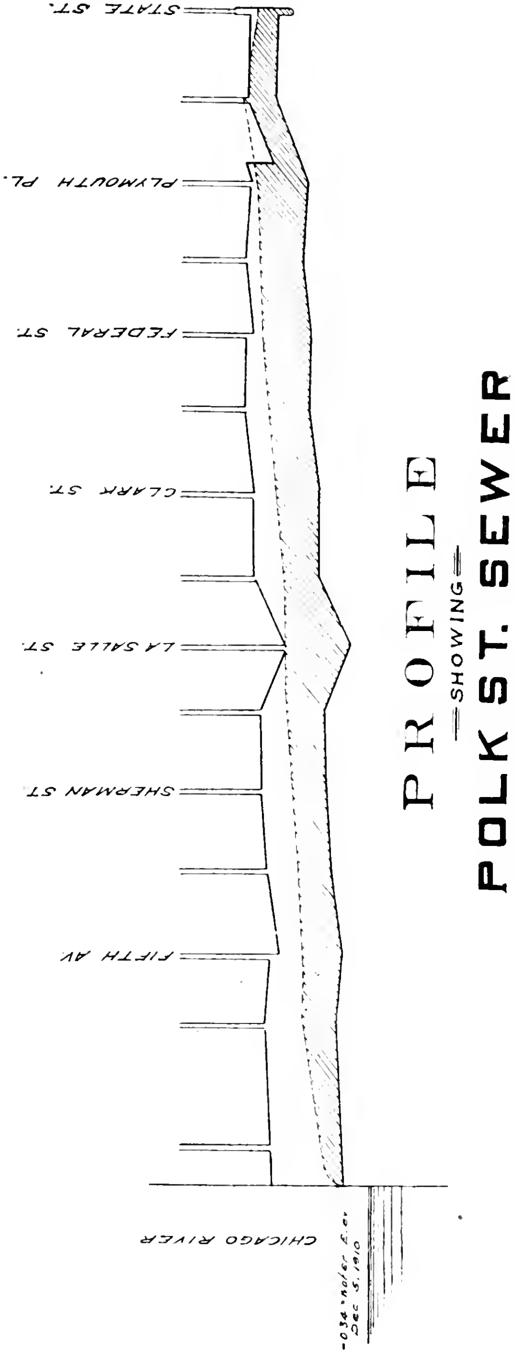

Fig. 8.—Sewer Clogged with Sediment.

These sewers are 3 ft. in diameter at the outlets where they empty into the South Branch of the Chicago River, and are 2 ft. in diameter at the summits, which are located between State street and Wabash avenue. From the summits these sewers slope to the east to a main sewer in Michigan avenue which is 4 ft. in diameter at the outlet at the main river, and 2½ ft. in diameter at the summit near Congress street, and thence sloping south to the intercepting sewer at Twelfth street. There are brick sewers 2 ft. in diameter in the north and south streets extending from Randolph street north to the main river. South of Randolph street in the north and south streets, there are tile pipe sewers 12 in. in diameter that empty into the brick sewers in the east and west streets, having a summit in the middle of each block.

Insufficient Size of Sewers.—The sewers in this district were designed and built 50 years ago on a liberal scale to provide for the storm-water run-off that was to be expected, and proved sufficient for the conditions of the following 25 years. During that period there were no sky-scraper buildings, the pavements of the streets were not impervious, there were considerable areas of private land not roofed or paved, and there was no serious difficulty in draining the streets and the buildings. The conditions of today, with large buildings, impervious pavements, and private property, nearly all covered with either roofs or paved areas, require a capacity much larger than these sewers possess. With the conditions that we will have ultimately, the sewers should have a capacity of about five times the capacity of the present sewers.

During recent years, many complaints from owners of buildings as to lack of drainage have made apparent the inadequacy of the entire system of sewers in this district. These complaints are increasing as the years go by, and the conditions that cause them are growing. It is not remarkable that sewers that were designed and built 50 years ago are no longer adequate to care for this district, which has been completely built up and is now being rebuilt with enormous modern buildings.

Sewers Not Self-Cleansing.—The surface of the streets in this portion of the city was originally 6 or 8 ft. below the present grade of the streets. The sewers necessarily were built shallow and with flat grades, and for this reason the current is sluggish and sedimentation occurs in all of them, it not being possible for them to be self-cleansing. At the present time these sewers are nearly half full of mud and water, even in dry weather. This is due partly to the fact that it is impossible to keep them clean, and partly to the fact that such a vast amount of water is used in the buildings in the district.

Obstructions in Sewers.—In several places these sewers are obstructed by pipes passing through them. It is probable that these pipes were laid in the early days when the surface of the street was so low that it was not practicable to lay water mains over the sewers. The pipes are obstructions to the flow of the sewage, and in many cases cause very considerable deposits, and they prevent the proper cleaning of the sewers.

Cleaning of Sewers Difficult.—As has been stated, these sewers are not self-cleaning, and the work of cleaning them becomes more and more difficult. This difficulty is due partly to the fact that they are generally submerged, particularly the small pipe sewers, so that it is difficult for the men to pass rods and chains through the sewers. The vast amount of traffic on the streets, particularly the street car traffic, makes it impossible to place derricks over the manholes and to scrape the sewers in the usual manner, except by having the men work after midnight and before five o'clock in the morning. This night work is not only very expensive, but it is not as effective as it would be if it were under the supervision that could be given day work. In this district, more than elsewhere, it is important that the sewers be self-cleaning.

Grease in Sewers.—There are a great many restaurants and hotel kitchens in this district, and sufficient precaution is not taken to prevent the grease from these kitchens passing into the sewers. In fact, an examination of most of the tile pipe sewers shows a large accumulation of grease. This grease in the sewers which adheres to the sides of the sewers and to the sides of the manholes, very materially prevents the flow. In many cases of complaints from buildings, the trouble is due primarily to this accumulation of grease in the main sewer and in the private drain from the building.

Damage Caused by Large Buildings.—The construction of the modern large buildings, and particularly the construction of curb walls extending to a depth of over 30 ft. below the surface, has caused settlement of the sewers. A recent case of this sort is the sewer in Eldridge court west of Michigan avenue, which has apparently collapsed, this being caused by settlement due to the construction of the Karpen building. Naturally the settlement of the sewer, even though it may not collapse, will cause sedimentation to take place, thereby obstructing the flow.

Drains for Buildings.—All of the modern buildings have deep basements, and power pumps are installed that force the sewage from the buildings into the main sewers under pressure. Such buildings have very little trouble; but the water that is forced into the sewers from them is forced back through the drains into the basements of buildings of the old type, particularly when it rains, at which times the sewers are insufficient in size to carry off the water. This forcing of the water back through the drains has the effect of forcing the silt from the main sewers into the drains, thereby further damaging the drainage from these old buildings. The connections from the buildings to the main sewer are frequently laid too low and at too flat a grade, so that these pipes are often submerged, and in consequence the flow through them is very sluggish, they become filled with sediment, and are completely obstructed.

Maintenance of Catchbasins Difficult.—All of the streets in this district are filled from curb to curb with various pipes and conduits. Some of these conduits are laid along the sides of the streets where catchbasins are built, and in some cases interfere very seriously with the effectiveness of the catchbasins, and particularly with the connections from the catchbasins to the main sewer. It is almost impossible to clean some of these basins. and in others the connecting pipes have been placed below the conduits and are so low that a comparatively small amount of dirt swept into the basins will completely fill the mouths of the outlet pipes. When streets are paved, it is almost impossible to find room to build the necessary additional catchbasins. Recently the construction of the new curves connecting the street-railway tracks has made it necessary to remove the catchbasins at the curb corners, and it has been difficult to build the new basins necessary. In some cases connecting pipes from the street inlets to the adjacent catchbasins are laid over conduits, and they are so shallow and are laid at so flat a grade that they soon fill up with the detritus washed from the pavement.

Summary of Conditions.—It has been shown that these sewers are of insufficient size; that they have been badly damaged by the construction of buildings and other structures; that they are not self-cleaning, and that it is practically impossible to keep them clean.

Present Sewer System Should Be Condemned.—The more this problem is studied, the less possible it seems that we will be able to use any of the present sewers. A system of relief sewers, giving additional outlets to the main sewers, will not be sufficient, for the reason that the greatest trouble is from the small lateral sewers. The entire sewer system should be condemned and replaced with an entirely new system that will be completely up-to-date and take care of all possible future developments of the district.

Reconstruction Necessary.—The reconstruction of these sewers should have been commenced years ago, but it was impossible to make any intelligent plan for a new system of sewers that could be used in connection with the proposed subways for transportation and other uses. The cost of such a system of sewers would be so great that it would be manifestly absurd to build them with the idea that they would be torn out when the subways were constructed. It was impossible to prepare any definite plans for such sewers until definite plans had been adopted for the construction of subways. These subway plans have now been prepared, and it is the purpose of this report to suggest how the sewerage problem can be solved in connection with the construction of these subways.

Essential Features of New Design.—The new sewers should be designed in accordance with certain fundamental principles:

1. There should be a complete separation of storm-water from the sewage, necessitating the construction of separate systems of sewers.

2. All storm-water drains, without exception, should flow by gravity to the river and should be free from inverted syphons. No storm-water should be pumped.

3. All storm drains should have ample capacity to carry off promptly all rain from roofs and pavements.

4. Inlets from streets to sewers should be so arranged as to permit the flushing of pavements. It may be necessary to omit catchbasins on account of the construction of subways.

5. At necessary points arrangements should be made for connections with water mains for the purpose of flushing the storm drains.

6. Large sedimentation basins should be constructed along the line of the storm drains near the outlets to prevent the discharge of detritus into the river.

7. All sanitary sewers should, so far as is practicable, flow by gravity to the river with a minimum amount of pumping and a minimum number of inverted syphons.

8. All sanitary sewers should be so designed as to be self-cleansing.

9. All sanitary sewers should be discharged into the South Branch of the Chicago River.

10. If possible, arrangements should be made that will prevent the discharge of sludge from the sanitary sewers into the river.

11. The sewer pipes of all adjacent buildings should be so arranged that all rain-water will be discharged into the storm drains, and all other sewage and waste water will be discharged into the sanitary sewers.

12. It may be necessary to require the owners of buildings to lift the sewage from basements so that it will discharge into sanitary sewers laid at an elevation higher than that of the basements. All sewage from that part of the building at or above the street level should discharge into the sanitary sewers.

13. All sewage and drainage from the subways should be lifted and discharged into the sanitary sewers.

Importance of Problem.—The most important problem in the designing of the new sewer system is the determination of the amount of water that will be delivered to the sewers. With the streets paved in a modern fashion, with shallow gutters, there is little storage room for storm-water on the surface of the streets. If the sewers are not of sufficient size to take the rain as fast as it falls on the pavements and on the roofs, the water will accumulate on the pavements and will overflow into the entrances of the subways; at the same time, the sewers being full, it will be impossible to drain the basements of the adjacent buildings, and a flooding of the subways and the buildings will result.

Determination of Amount of Sewage.—The determination of the amount of sewage to be discharged from the buildings is comparatively easy, as it will equal in amount the water supplied to the buildings. Elaborate estimates have been made of the amount of water that will probably be consumed in this district when it is completely rebuilt with modern buildings, and water mains of the size necessary to supply this water will be installed.

Sanitary sewers that will take this water from the buildings should have as great a capacity. The volume of sewage from the buildings will be constant day after day, and will not vary much during the hours of the day.

Determination of Amount of Storm-Water.—To determine the necessary size of the storm drains to carry off the rainfall is more difficult. Ordinarily in designing sewers provision is not made for taking care of all of the rainfall in times of storms of exceptional severity; that is, it is not considered bad practice to design a sewer that will prove insufficient in size two or three times in a period of ten years. Because of the great damage that would be done by the flooding of the subways, the storm-water drains should be of sufficient size to take all of the water that could be reasonably expected, judging from the experience of the past. In designing sewers in Chicago, particularly in the outlying districts, it has been customary to assume that only a small portion of the rainfall will enter the sewers during the time of the rainfall; that is, we assume that the larger portion of the rain will be held back on the surface of the ground, and will enter the sewer slowly, and that a considerable portion will not enter the sewer at all. In designing the new storm drains for this central district, we must assume that all of the rain will enter the drains as rapidly as it can flow from the various parts of the roofs and pavements to the nearest inlets, and that the volume of the flow through the sewers during any period of time will equal the volume of rain during the same period of time. Sewers designed on this principle will have a much greater capacity per acre of land drained than any sewers heretofore built in the City of Chicago.

Separate Systems Necessary.—The volume of the maximum rainfall will greatly exceed the maximum volume of sewage from the buildings. If combined sewers are built that will receive and carry the sewage from the buildings, as well as the storm-water, the sewers will be so large that in dry weather the stream of sewage will be comparatively small, and will be sluggish, so that it will be impossible for these to be self-cleansing. If, in addition to this, street sweepings are washed into the sewer the sedimentation will be increased, and the sewer will become very foul and offensive. A majority of authorities on sewerage advocate a separate system of sewers under all conditions. In this district it is particularly necessary, for the reasons indicated above, that the separate system be established.

Flushing of Drains.—The flushing of pavements is advocated by many authorities on street cleaning. It is usually opposed by officials who have charge of sewer cleaning, but the opposition is seldom effective, for the reason that the public is more desirous of having clean pavements than clean sewers. The flushing of the pavements of this district appears to be inevitable, and it is advisable that such provision be made as will permit this with the least possible harm to the sewerage system. It will be impracticable to construct catchbasins that will prevent the washing of detritus from the pavements into the storm-drain. During dry weather this detritus will lodge in the drains, and the water from the flushing of the pavements will not have sufficient force to carry it along. If this sediment is not mixed with sewage from the buildings, it will not be particularly offensive, and no harm will result, provided the sediment is flushed out of the drains in times of rain. For fear of the smaller storm drains being obstructed, it is advisable that pipes be laid connecting the water mains with the upper ends of the drains, provided with the necessary valves so that it will be possible to flush them.

Drains Free from Inverted Syphons or Pumps.—Because of the large amount of sediment that will be washed into the storm drains, it is absolutely necessary that they should be laid on proper gradients, and that they should be entirely free from inverted syphons. An attempt to pass such a storm drain beneath the subway by means of an inverted syphon would certainly result in the syphon becoming absolutely obstructed with sediment. The construction of a system of storm drains laid at a level lower than that of the river, thereby requiring the use of pumps, would be very unwise, for the reason that it would be necessary to install machinery of so great a capacity, that all of it would not be used except once or twice in a period of years, and at the same time it would be necessary to maintain all of this machinery ready for instant use. The installation and operation of such machinery would be very expensive, and as a matter of fact, there need be no difficulty in installing gravity storm-drains in connection with a well designed system of subways.

Sedimentation Basins.—This general arrangement will result in a large amount of sediment being washed into and through the storm drains and discharged into the river. In view of the growing opposition of the Federal Government to such practices, it is advisable that the storm drains be arranged to discharge through large sedimentation basins, which should be located near the outlets. Apparatus could be installed that would remove the sediment from the basins much more economically than it is now possible to clean the ordinary catchbasin in the streets.

Inverted Syphons and Pumps in Sewerage System.—In the case of the sanitary sewers it is permissible to use inverted syphons and pumps if the conditions absolutely require them. The flow through the sanitary sewers is fairly constant at all times, and there is very little danger of sedimentation in the inverted syphons. However, it is advisable to avoid anything of the sort. The particular objection to the pumping of sewage is the cost of operation. If all of the sewage were carried through low-level sewers and were lifted by pumps it would be necessary to pump all of the water that would be delivered to all of the buildings in this district. The greater portion of this water is discharged from the upper stories of the buildings, and it should not be difficult to arrange the sewerage system so that all water discharged from the upper stories of the buildings would be carried by gravity to the river. The sewage from the ordinary basements of buildings located near the river could be discharged in the same manner, but it would not be possible to take the sewage from basements at a considerable distance from the river without pumping.

No Sewage Discharged Into Main River.—It is very important that no sewage be discharged into the main river, but that the sewers be so built that the sewage will be discharged into the south branch. While it is true that there is a flow in the main river from the lake, it is also true that a momentary fluctuation in the level of the lake will sometimes cause a corresponding reversal of flow in the main river, and a large flood in the valley of the north branch may cause the normal flow in the main river to be reversed for several hours, and any sewage in the river, or any sludge in the bottom of the river, might be washed into the lake. It is hardly conceivable, however, that any flood would be so great as to reverse the flow in the south branch of the river, and it is therefore apparent that the discharge of the sewage into the south branch is much preferable to its discharge into the main river.

Anticipate Future Purification of Sewage.—In the designing and the building of these sewers it is advisable to anticipate the future construction of an intercepting sewer that will convey all of the sewage of this district to some convenient place for purification, as the population of the City of Chicago will undoubtedly increase to such an extent that the mere dilution of its sewage will not be sufficient. It will be necessary to install apparatus that will purify, at least partially, the sewage before it is discharged into the Sanitary District channel.

Sludge Tanks.—It is possible that some apparatus might be installed at the outlet of each sewer that would to some extent purify the sewage and thereby decrease the pollution of the river. It is quite probable that some form of a sludge tank could be installed that would materially decrease the amount of sludge that is now being discharged directly into the river. It is a fact that a vast amount of sludge has accumulated in the river and in the main channel of the Sanitary District, and the Federal Government is taking notice of this accumulation.

This sludge problem is one of the most serious problems that is confronting Chicago today, and, in the designing of these sewers, it should receive very careful attention.

Separation of Roof Water from Sewage of Buildings.—It will be necessary to require the owners of buildings to rearrange the sewer pipes of all buildings so that all rainwater will be discharged into the storm drains, and all other sewage and waste water be discharged into the sanitary sewers. The neglect of this rule would result in the overloading of the sanitary sewers during time of rainfall, or else in the discharge of sewage into the storm drains, where it would lie stagnant and putrefy.

Sewage from Basements to Be Pumped.—The sewage from all portions of the buildings above the elevation of the sanitary sewers would discharge directly by gravity into the sewers. The sewage from the basements that are below the level of the sewers would have to be lifted by pumps. This is now being done by the owners of modern buildings, and it would not be a hardship to require it in all cases. There may be difficulty in working out the details of this requirement, but it should be no more difficult than the adjustment of other questions involved in the construction of the subways in front of the buildings.

Report of Mr. Arnold.—If a complete system of subways is built in accordance with the general plans and recommendations contained in the report of Mr. Bion J. Arnold, dated January 31, 1911, it will not be difficult to arrange the system of drainage and sewerage to conform to the foregoing requirements.

Sewers on Each Side of Street.—The lack of space between the pavement and the tops of the cars in the high-level subways will prevent the crossing of these subways with drains and sewers except where these subways are depressed. It follows that it will be necessary to lay a drain and a sewer on each side of such subways. In general the direction of the principal sewers and drains will be parallel to such high-level subways. The sewers and drains in cross streets where there are low-level subways will necessarily be limited in length by the intersecting high-level subways. In such streets it will be possible to obtain the necessary service with one sewer and one drain, but it is preferable to adhere to the general plan of providing one sewer and one drain on each side of the street near the buildings, leaving the space in the centre of the street over the low-level subway for other utilities.

Space for Sewers and Drains.—Where the high-level subways contain but two tracks, there will be ample space beneath the sidewalk for both sewer and drain, as well as for other utilities. Where there are four tracks, the requirement of entrances to the stations between the tracks necessitates the placing of one track beneath the sidewalk, leaving a narrow space for the sewer and drain and a very limited space for other utilities. It will be necessary, therefore, to lay the principal lines of such utilities in other streets, which can be done without any difficulty.

Objection may be raised to the narrow roadway shown in the typical cross-section of a four-track subway (Plate No. 13), and a remedy may be suggested by narrowing the sidewalk and placing the car nearer the building line. This must not be done if it results in eliminating the necessary space for the sewer and drain.

Where the drain serves a small area (one or two blocks) but little space is required for it, but where it serves a large area it may be several feet in diameter. In general it is advisable that the main drains be laid in streets other than those containing four-track subways, and this can be done with possibly one or two exceptions.

Materials of Construction.—In streets where high-level subways are built, it will be necessary either to incorporate the storm drains in the roof of the subway (particularly near the summits of the sewers), or to suspend the drains along the side walls inside of the subways. The sewers will be suspended in a similar manner at an elevation somewhat lower than that of the drains. For this form of construction iron or steel pipes are apparently the most suitable material, provided the sizes are kept within reasonable limits. Where the storm drain serves as an outlet for a considerable area, the necessary size of the drain will require some other material, and for this purpose reinforced concrete is suitable. The concrete drain will be incorporated in the structure of the subway and should be inside the outer walls. As the subways approach the river and are correspondingly depressed, the drains and sewers will emerge through the roof and will continue to the outlets as independent structures.

Progressive Construction.—The construction of the subway system by progressive stages, extending over a number of years, would not only prolong the present intolerable condition of inadequate sewerage in many of the streets, but would make it very difficult to maintain some of the sewers in as good condition as they are now. If it is possible to finance the project, a definite determination should be made as to the extent of the subways, and the work, especially in this district, should be pushed to completion with as little delay as possible. In laying out the progressive steps of the work, some consideration should be given to the requirements of the sewerage system. Some of the first subways would lead to crossings of the river, and would naturally afford outlets for new drains. A subway along State Street, being near the summits, could be temporarily connected with the existing sewers without causing any trouble. On the other hand, it would be very difficult to care for the sewers cut off by a high-level subway in La Salle Street, if such subways were built in advance of the construction of the necessary sewers in the streets east of La Salle Street. In all streets where subways are not to be built, sewers and drains should be constructed as soon as outlets can be provided for them.

Cost of New Sewer System.—It is impossible to estimate the cost of the new system of sewers and drains in advance of the preparation of definite plans. It is probable that the cost will be between $1,000,000 and $2,000,000.

Special Assessment.—If the new system of sewers could be built independently of the subways, the entire cost should be assessed on the property benefited. Any portion of the system which forms a part of the subways could not be considered a local improvement unless the whole subway system were so considered. It is possible that an assessment might be confirmed to pay for the cost of some of the sewers built in streets where subways are not built, but it is very doubtful, since these sewers are necessitated by the construction of the subway system. It is almost certain that the courts would not consider the subways or any portion of the system as a local improvement.

Cost of Sewers Included in Cost of Subways.—Whatever arrangements are made for the financing of the subways, ample provision must be made for the reconstruction of the entire system of sewers in the district under consideration. The fact that a small portion of the existing sewers may not be disturbed by subway construction is not a sufficient reason for leaving them as they are. The entire cost of the complete reconstruction of the sewer system of this district should be included in the cost of the subway system.

Respectfully submitted,

C. D. HILL,

Superintendent Bureau of Sewers.

THE SEWAGE DISPOSAL PROBLEM IN THE UNITED STATES AND ABROAD

LANGDON PEARSE, M. W. S. E.*

Presented January 30, 1911.

Recently, while investigating the disposal of sewage in Europe and England, I found several interesting and curious facts concerning the sewerage of London. Prior to 1815 it was a penal offense to discharge domestic sewage into the sewers. Cesspools were used until, in 1847, a regulation was passed making compulsory the discharge of all house drainage into the sewers. In less than six years over 30,000 cesspools were abolished. By 1849 the volume of sewage became so great that the self-purification of the River Thames was absolutely inadequate. The question of sewage disposal was agitated until, in 1856, the present scheme of intercepting sewers was begun and the extension and improvement of the system has been carried on ever since. I mention this since it is of interest to know that at the very time when the sewage-disposal problem was first faced so markedly by the city of London, Mr. Chesbrough was making a trip abroad in order to learn what he could of advantage in planning a sewerage system for the Chicago of his day and providing for the future. At that time Chicago was a small town and London was the largest city of the world. Now the proportion is about four to one, as London has from eight to nine million inhabitants and Chicago about two and a quarter million. In population Chicago is running a good race and also encounters the same difficulties with sewage disposal.

This evening I want to give you a brief sketch of the status of the sewage-disposal problem from the viewpoint of a specialist, and to show you the general trend of thought in this country and abroad concerning the best methods of handling the question. In the first place, we may look at the matter either in the light of preventing pollution of a water supply, or of the abatement of a nuisance. Those are the two issues to consider. Usually, where the water-supply problem does not enter into the question, there is the matter of nuisance,—particularly in Germany, where many water supplies are filtered, or taken from ground water at a distance from the river. The general trend abroad is that the effluent to be discharged into a stream shall be no worse than the general character of the stream itself. This is also in accordance with some recent judicial decisions in England, particularly in connection with the Birmingham sewage-disposal works. Such a criterion, of course, allows leeway, in that more or less pollution may enter the stream, but it does not prevent nuisance altogether. The Continental idea is to use the self-purification

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power of a stream as far as possible whenever sufficient dilution is available, while in the eastern states of the United States we are gradually outgrowing the idea that all sewage must be highly purified, and we are looking towards effecting a sufficient degree of purification for the purpose in hand and making use of any reasonable dilution wherever a water supply is not directly concerned. With a lightly polluted source of water supply, the purification of the water by filtration or other adequate means for bacterial removal is usually cheaper and safer than to purify the sewage to a high degree, even if the dilution be very great. The purification of the water supply also affords protection, not only against continued sewage pollution, but also any chance pollution, as from shipping.

The first and most immediate solution of the problem confronting large cities was dilution. In the case of the large cities located on or near the seacoast, the sewage could readily be discharged into a river, a tidal estuary, or the ocean, where there was dilution and sufficient dissolved oxygen in the water to carry on the so-called self-purification,—that is, oxidation of the organic matter. Sewage has often been discharged into drinking-water supplies on the same basis without ill effect so long as the pollution was slight and the distance relatively great between the source of pollution and the waterworks intake. But, with the rapid growth of population, the amount of sewage increased and the water supply became so badly polluted as to be dangerous to health. In other cases the dilution was not sufficient to oxidize the putrescible matter, and nuisances developed.

I shall now discuss the matter from the sewage disposal standpoint with the intent of preventing nuisance, assuming that the sewage is removed entirely from a water supply. This has been the case in most of the larger schemes in this country and abroad. The first development was in chemical precipitation by the addition of coagulants. This process, I think, was being tried in England even as early as 1850, about the time when Mr. Chesbrough was making his trip. Later, methods of sedimentation were taken up, and in the course of time the septic tank developed, in which the sludge was allowed to accumulate in contact with the incoming liquid. In a few years, experience and study showed the difficulties of the septic tank, and the so-called Travis or Hampton tank was invented,—a double-deck type in which the sludge is deposited into a lower chamber from the liquid flowing up above, and a certain portion of the incoming fluid is diverted through this sludge chamber to wash away the products of decomposition. So-called colloidors, or slats, are hung in the settling portion of the tank to increase the settling effect. Today, the trend seems to be away from the septic tank and the Hampton tank towards the so-called Emscher tank, devised by Dr. Imhoff for the Emscher Sewerage District in

Germany (Fig. 1). In this tank there are two decks or compartments. In the upper one the suspended matter settles, the sludge dropping through a slot into the lower, or sludge-digestion chamber, where decomposition can progress without in any way polluting the incoming liquid. This has the advantage of providing a very fresh effluent, and is a direct improvement

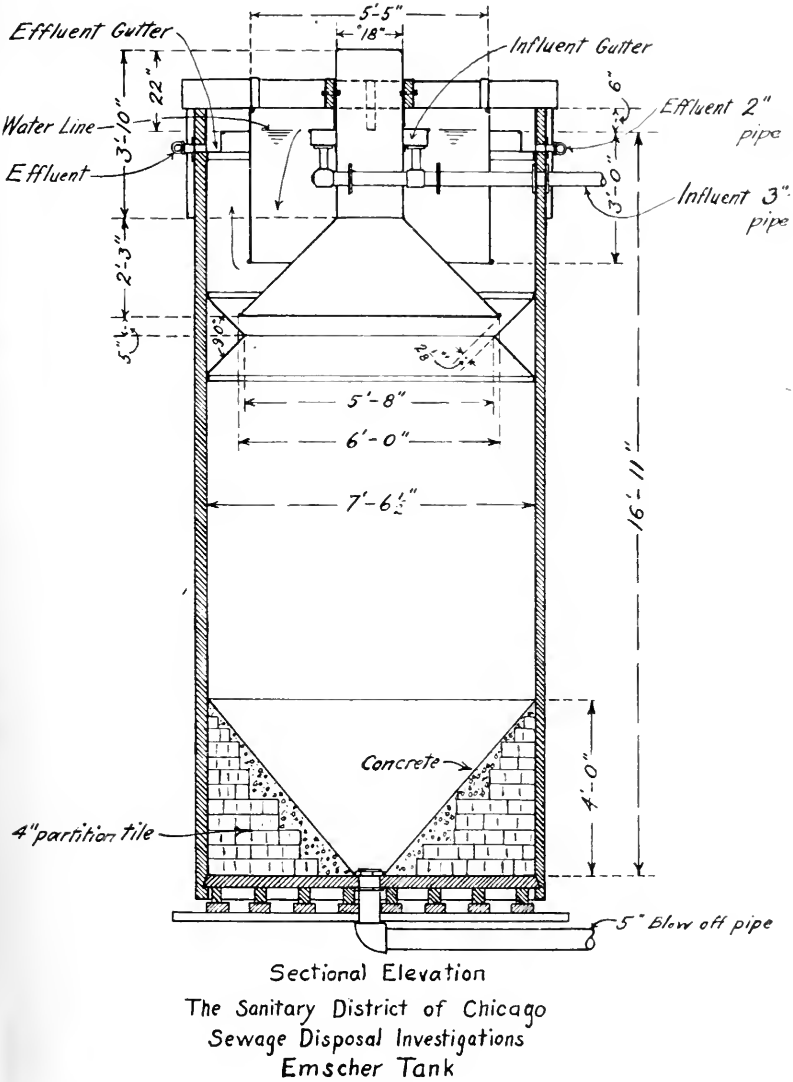

Fig. 1. The Emscher Tank.

over the old-fashioned septic tank, where for one or two months a year more suspended matter may be discharged than arrives in the influent. An effluent of that character may easily require more dilution than the crude sewage itself.

Such is the general trend of the preparatory end of the problem, namely, the removal of the suspended matter from the sewage. The next, and probably the most pressing question today, is how to handle the sludge. The fact is now generally accepted that, while a certain portion of the deposit in a septic tank may liquefy, there is bound to be an accumulation of sludge, and a definite amount must be removed yearly, just as in any sedimentation process. This sludge must be disposed of no matter what process is used. It is akin to the old law of the conservation of matter. The accumulation of sludge will not disappear in any magic fashion, but must go somewhere, if it does not remain in the tank. Our experience is that it will be discharged by the tank at the time of the year when it is least desired,—in the warm months of the summer. I believe that the present problem is more nearly solved by the use of the Emscher tank, by its depth of 30 to 40 ft., because it produces a very compact sludge which contains a number of gas bubbles under pressure, which will expand when the sludge is run out on a drying bed, allowing the sludge to drain more quickly. This statement, however, has not been verified by us at the experimental testing station of the Sanitary District. Our tank was built in June, 1910, and as yet, we have not removed any sludge. We do, however, know from experiments in this country that the idea is correct, and we have also the German experience to guide us.

You will realize how large the quantity of sludge is when I tell you that in the various cities of this country and abroad, there is retained in the settling or septic tanks from 1½ to 8 cu. yds. per million gallons. Sludge has an average water content of from 80 to 95%. In planning for a city located like Chicago, the question of sludge disposal cannot be passed over casually. It is a real, live issue, since the sludge should not be put into the lake, and cannot be put into the canal. Some method of land disposal therefore must be figured on. If the sludge be dried on sand-beds, septic or sedimentation sludge requires about 30 days to be spadeable, whereas it is claimed for the Emscher tank sludge that from 3 to 7 days are sufficient. The resulting air-dried sludge can be used for filling or even burned, with the addition of a small amount of fuel. Probably by the use of tank boats the sludge could be carried down the canal to waste land, and there treated or disposed of.

In taking up the sewage disposal proposition from the standpoint of increasing the dilution capacity of the Drainage Canal, no matter what preliminary steps are adopted,—for instance, screening or sedimentation,—the effluent of the process is always going to be putrescible; in other words, will not be stable and does not contain enough dissolved oxygen to carry on its own purification. While such a method is successful where sufficient water is available for dilution (as is the case with the Drainage Canal for the present), it would not be applicable everywhere. If partially purified sewage is to be discharged into a watercourse where there is very little flow, or perhaps none at all, it is not sufficient to settle part of the suspended matter. Further means of removing the putrescible matter and making the liquid more stable must be adopted.

Several processes have been evolved in the past, such as intermittent sand filters, then contact beds, and of late years, the sprinkling filter, which today is generally recognized as being one of the best means available for the purpose, although it has its limitations; in fact, all devices in sewage disposal have their limitations, but today the sprinkling filter is the most efficient way of turning the putrescible effluent of the tank into a stable liquid by sprinkling the liquid over beds of crushed stone and allowing nitrification to go on under favorable conditions. But no one now claims that such a filter is all-sufficient for removing bacteria. Perhaps 80% may be removed with a sprinkling filter operating under average conditions. Sometimes we have removed as high as 99%; but with a count of a million, even if 99% are removed, there are still 10,000 bacteria left in a cubic centimeter, and with the 10,000 largely composed of bacteria of uncertain character, the effluent is not safe for drinking purposes. At the testing station, one adventurous spirit drank some of the effluent of a sprinkling filter without any ill effect thereof, but such a procedure is not recommended. However, when bacterial removal is required, the effluent can be treated by disinfecting it with chloride of lime, which readily and cheaply removes all the bacteria. This is a modern finishing process and has been adopted in some of the plants of this country, particularly Baltimore, where an effluent thoroughly free from bacteria was desired to protect the shellfish industry below the outlet of the sewage disposal works.

Now, you may inquire what led the Sanitary District to consider the matter of sewage disposal by methods other than dilution. You have seen very vividly, in the case of Chicago, how any arrangement for the sewage disposal of a city, and, I might add, for the water supply of a city, is quickly outgrown under the conditions of rapid expansion which exist in the United States today. We have figured, in accordance with the charter of the Sanitary District, that if the Government only permits us to take 10,000 cu. ft. per sec. from the lake, when we reach a population of three million, we shall have exhausted the capacity of our canal for self-purification. In other words, the canal will not be able to effect the purification necessary to prevent nuisance. Therefore when that time comes, in 1920 or earlier, further steps must be taken to increase the capacity of the canal. This means that enough of the putrescible matter must be removed from the sewage so that it can still be discharged into the channel and find enough oxygen in the water to oxidize the organic matter. The first step probably will be to screen the sewage to remove the suspended matter that is offensive to the sight. While this may remove 15% or 20% of the suspended matter, it will not help the putrescibility of the liquid very greatly. The next step would be the installation of settling basins at suitable points and then finally, whenever we have to go so far, sprinkling filters might be installed in certain districts of the city. That, however, is a rather remote contingency at the present time. We are making a thorough study of these matters at the sewage-testing station, so I do not propose to discuss them tonight. At a later date I hope to give you a talk which will take up the entire scheme of our work, whereas this evening I am only going to take up the subject of sewage disposal in a general way.

There is one question which is very often asked me, even by engineers, and that is, why is it necessary to study the sewage of a city in such detail, and is not all sewage alike? People fail to realize that there is a vast difference in sewage, not only between cities, but between cities in this country and abroad. That difference comes partly from the habits of the people, in part from the amount of water that is used, the great variation in the amount of water, and then from the makeup of the sewerage system itself.

To illustrate the difference in the composition of sewages in this country and abroad, I have prepared two tables. One of them (Table I) is compiled from various published results, and the other (Table II) is taken from a report made by George A. Johnson on the Sewage Disposal of Columbus, Ohio. In Table I typical analyses are shown from the cities in the United States, selected more particularly because testing stations or plants have been built and operated at each, and also with a view to illustrating the wide difference in the sewage. From the chemical analyses in parts per million, the range in the constituents is shown. Boston, for instance, is a city largely of domestic tastes, without much heavy manufacturing; Waterbury has a good deal of metal industry and light manufacturing, yet, in neither are the industrial wastes exceedingly prominent. At Gloversville, however, the principal industry is tanning and allied processes. Consequently there is a large amount of industrial waste in its sewage. Worcester is a manufacturing city, peculiar on account of the acid wastes from the big wire mills of the U. S. Steel Corporation. The acid wastes at times are so strong that the alkalinity of the sewage is exhausted and the sewage may become actually acid. For Chicago, I am showing the results of the tests in the 39th street intercepting sewer, giving you the average for the year 1909-10. On the basis of the analysis in parts per million, the sewage of Chicago is very weak as compared with some of the other cities. But when the chemical constituents are figured as grams per capita, it shows up very strongly, even when compared with the large English manufacturing cities. There is a remarkable amount of chlorine in the sewage of Boston due, not to domestic pollution, but to the infiltration of salt water. At times in Chicago we find very high chlorine for short periods, which can be traced to the salty discharges of ice cream factories. The alkalinity in the sewage varies more or less with the hardness of the water used for drinking purposes. Chicago, for instance, has a hard water from

TABLE I.

COMPARATIVE ANALYSES OF CRUDE SEWAGE OF BOSTON, COLUMBUS, WATERBURY, GLOVERSVILLE, WORCESTER, AND CHICAGO.

(Parts Per Million)

	Boston, *a* 1905-07.	Columbus, *b* 1904-05.	Waterbury, *c* 1905-06.	Gloversville, *d* 1908-09.	Worcester, *d* 1908.	Chicago, 1909-10
Nitrogen as:						
Free Ammonia	11.4	11.0	7.8	12.0	22.2	8.8
Organic Nitrogen	9.1	9.0	14.8	23.0	....	7.6
Nitrites	0.0	0.09	0.14	0.38	....	0.11
Nitrates	0.04	0.20	1.52	0.88	....	0.35
Oxygen Consumed	56†	51†	46†	95†	117	38‡
Chlorine	2300**	65	48	158	57	40
Alkalinity	125	350	41	233	....	208
Suspended Matter:						
Total	135	209	165	406	258	141
Volatile	91	79	115	229	166	81
Fixed	44	130	50	177	92	60
Free CO_2	..	27	18	10	....	..
Fats	..	25	26	48	....	23

*a*From Winslow and Phelps, "Investigations on the Purification of Boston Sewage in Septic Tanks and Sprinkling Filters." Technology Quarterly, Vol. XX., No. 4, p. 410, Dec., 1907. (See Note.)

b George A. Johnson, "Report on Sewage Purification at Columbus, O.," pp. 26, 34.

*c*Wm. Gavin Taylor, "Waterbury Sewage and Its Septic Action," Eng. News, Vol. 61, p. 597.

‡Sample immersed in boiling water for 30 minutes.

† Sample is boiled 5 minutes.

** Chlorine from Water-Supply Paper No. 185 (U. S. Geol. Surv.), pp. 111-114.

*d*Eddy and Vrooman, Report on Sewage Purification, Gloversville, N. Y., p. 59.

Note.—Nitrogen values as given are corrected to be comparable with other figures.

TABLE II.

ESTIMATED AVERAGE QUANTITIES OF PRINCIPAL CONSTITUENTS IN GRAMS PER CAPITA DAILY OF THE SEWAGE OF VARIOUS CITIES.

City. Combined or Separate System.	Columbus, Ohio, Combined.	Small Mass. Cities. Separate.	London, Eng. Combined.	Manufacturing Cities, Combined.	Chicago, 1909-1910, Combined.
Average daily flow of sewage, U. S. gallons, per capita...	121	95	54	..	289
Oxygen consumed:					
Total	30	13—	25	50	42
Dissolved	14	..	..	..	..
Suspended	16	..	..	..	..
Nitrogen as:					
Total	14.4	9.7	13.0	13.0	18.5*
Organic:					
Total.........	6.2	4.7	1.5	..	8.3
Dissolved.....	2.4	..	..	..	..
Suspended.....	3.8	..	..	..	..
Free Ammonia....	8.2	5.0	8.0	5.5	9.6
Chlorine	32	16	24	44	44
Dissolved Matters:					
Total	410	85	157	268	..
Mineral	354	58	102	178	..
Volatile	56	27	55	90	..
Suspended Matters:					
Total	98	49	87	145	155
Mineral	51	11	41	69	89
Volatile	47	38	46	76	66
Total Solid Matters:					
Total	508	134	244	413	515**
Mineral	405	69	143	247	..
Volatile	103	65	101	166	..
Free Carbonic Acid...	13.6	..	..	..	..
Fats	19.1	..	..	..	26

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* Including Nitrates and Nitrites.

** Figure made up from determinations between Oct. 5 and Nov. 28, 1910. Average daily flow is 234 gallons per capita during that period.

Lake Michigan, whereas the water used in Columbus at the time of the tests was even harder than in Chicago.

The variation in flow in different cities is illustrated in the second table. The use of water and consequently the amount of sewage is less for the foreign cities than those of the United States. In London there is a sewage flow of 54 gallons per capita daily, and in some of the German cities it runs as low as 25 or 30 gallons per capita daily. In Chicago, on a yearly average, the flow at 39th Street pumping station is 289 gallons per capita per day. In Massachusetts, the sewage flow is very much less, however, as the water consumption ranges from 50 to 150 gallons per capita per day, whereas in Chicago it is about 235 gallons per capita per day on the yearly average. This, you can see, will greatly affect the problem of purification, both in the period of sedimentation and in the after treatment.

The modern idea is to build a sewer that will deliver the sewage to the outlet in as fresh condition as possible. This development is seen to greatest extent today in Germany, where sewers are built with smooth walls and very careful grades, in order to have no deposits, and also to obtain a rapid flow in order that the sewage may arrive at the places where it is to be treated or discharged into a water-course as fresh as possible. Such a procedure assists materially in preventing a nuisance. This may seem a strange doctrine, for probably all of you have heard the old saying "a running stream purifies itself," and then the modern qualification that a stream of sluggish flow will purify itself to better advantage. From the standpoint of protecting a water supply where the pollution is slight, the self-purification caused by sedimentation and the factor of safety provided by the time element in the destruction of pathogenic bacteria is very materially furthered by sluggish flow or quiescent conditions. But where the pollution is gross, as is usually the case in a sewage-disposal problem, the sewage or the mixture of water and sewage should be kept flowing as fast as possible in order to prevent sedimentation. The reason for this is that if sedimentation is permitted in a stream, sludge will accumulate on the bottom, and septic action will ensue which will rapidly exhaust the oxygen and interfere with the self-purification. If the stream flows through pools, those pools may become very live nuisances.

I am now going to speak to you of a number of typical developments of the sewage-disposal problem. First, I will call your attention to the Metropolitan Sewerage District (Fig. 2). This contains the city of Boston and its suburbs, and is one of the most highly developed and best organized districts in the country. The original scheme for the disposal of the sewage of Boston was the main drainage system built by the city, to an outlet at Moon Island, where large tanks were constructed, in order to store the sewage and discharge it on the outgoing tide. Subsequently, within the last fifteen years, two intercepting systems have been developed, the North system and the South, or high-level system. The North discharges at Deer Island, where the sewage is pumped out into a rapid-running tidal race, and the South system discharges at Nut Island. There is no treatment of the sewage except by coarse screening, which is merely to protect the pumps and hold back large floating matter, as garbage, dead animals, and the like. The total area served is 195 sq. mi., which is half that of the Sanitary District of Chicago and practically the same as the area of the city within the present city limits. The population is nearly a million inside the area indicated by the shaded lines. The pumping plant at Deer Island has vertical, centrifugal pumps, steam driven, somewhat similar in layout to the 39th Street Pumping Station.

Most of the largest cities in this country have combined systems of sewers. New Orleans, however, is one of the principal exceptions. On account of the low-lying land on which the city is built, a system of drainage has been developed as well as a system of sewerage. The sewage is discharged into the Mississippi River below the city, while the storm drainage is discharged into Lake Pontchartrain. The entire city is necessarily surrounded by levees.

New York City is one of the large cities which adopted the scheme of dilution in the early days, and is now facing the question of the prevention of nuisance. The solution is being hastened by the controversy over the proposed discharge of sewage from all the towns of the Passaic Valley into the lower harbor. The capacity of the tidal prism and the flow of the Hudson River is becoming insufficient to completely dilute and carry away the organic wastes discharged at frequent intervals on the North River and on both sides of the East River. The sewers in Manhattan and Brooklyn are very short, and the sewage is therefore very fresh. One of my Brooklyn friends says that on Sunday mornings the sound of the excreta dropping down into the sewers sounds like the distant discharge of a rapid-fire gun. The Metropolitan Sewerage Commission is now working on plans for the alleviation of the conditions in New York City. The Passaic Valley Sewerage Commission is studying the Jersey conditions. An intercepting sewer has been proposed in the Passaic Valley to bring all the sewage to a screening and settling plant and then discharge it out in the lower harbor at many points through submerged pipes.

Until recently Baltimore had no sewers for domestic wastes, although provided with some storm-water drains. A complete, separate system is now nearly constructed. The domestic sewage is carried to a disposal plant, where the sewage is to be treated in settling tanks and sprinkling filters, and is finally sterilized by the application of chloride of lime before discharge into the bay. This is being done to protect the oyster industry. The sludge is to be digested [illegible] separate sludge-digestion tanks so that the settling tanks can be frequently cleaned.

In the German cities the discharge of sewage into rivers has been studied very closely, because of the principle that treatment is necessary only to make the effluent as good as the stream and not increase the pollution; in other words, to provide an effluent which will not exhaust the dilution capacity of the stream. In Vienna there is a typical intercepting sewerage system, all the sewage being carried down below the city for discharge into the Danube. Dresden has also developed a typical intercepting sewerage system on both sides of the Elbe, bringing all the sewage to a common point for screening before discharge into the river. As yet, we have no example in this country of fine screening before discharge into a diluting stream.

Berlin is of interest because it affords an excellent illustration of the enormous development to which the pursuit of sewage disposal by sewage farming has led. The city proper covers an area of about 20,000 acres, whereas there are over 40,000 acres in the sewage farms. For Berlin, the scheme is a huge real estate speculation rather than a sewage-disposal plan. It is only a question of time before the city will sell this land at large profit and turn to modern biological methods. I mention this because many people ask why a sewage farm is not adaptable to this country. It is impracticable around Chicago on any scale, on account of the climate and the soil. The experience in England has been that the land soon becomes sewage sick, and will develop a nuisance if the application of sewage is persisted in. The most successful sewage farm in this country, to my knowledge, is the one at Pasadena, Cal., where the sewage is valuable from the standpoint of irrigation and the soil is very porous and sandy. English walnuts are raised with some profit, I believe. In Berlin, garden truck is raised, poor farms are operated, and cattle bred.

Paris likewise has a sewage farm. But to most of us, Paris is notable on account of the extent to which public utilities have been put under ground in convenient conduits. In a typical tunnel, the water pipes, telegraph wires, telephone wires, electric service lines and the sewers are carried side by side. Rails are also laid so that a small electric locomotive can enter and haul little cars around for the purpose of removing deposits from the sewer. I believe a public-utilities tunnel was proposed for the lower portion of New York City at the time of the planning of the first rapid-transit tunnel. It was never built because of opposition, the source of which seemed to be the contractors and others who were interested in the maintaining of the street-repair work and the American custom of continually ripping up the streets.

In Fig. 3 is shown a skeleton map of the sewerage system of London, which outlines the development up to 1909, and the present scheme of purification adopted there. Originally, as I have already said, the sewage was discharged directly into the Thames in the heart of the city and caused nuisances as far back as 1854. A Commission was appointed, and under the leadership of Sir Joseph Bazalgette, this body worked out the details of a system of intercepting sewers which is practically the same as the one in use today. For the last 25 or 30 years the discharge has been treated by chemical precipitation; that is, by the addition of lime to precipitate the suspended organic matter before the sewage enters the Thames—about 11 miles below London Bridge. In order to take care of the sludge from a population of eight or nine million people, five sludge steamers are traveling all the time carrying the sludge out into the North Sea and dumping it there. There are a number of pumping stations scattered over the city, some operated by electricity and some by steam, in order to lift the sewage from one level to another, in case the grades become too low for gravity flow. It is also interesting to know that extensive experiments on sewage disposal were carried on for over five years in London quite recently to secure, through biological purification, a means of extending the usefulness of their works, since in a few years the capacity of the present scheme will be exhausted.

Among the English cities, a number are distinguished for their pioneer work in matters of sewage disposal, of which Leeds is noteworthy, being styled the graveyard of more experiments and schemes in sewage disposal than any other city in England. I shall only speak briefly of two English installations. One is at Manchester, because the Manchester situation is analogous to that of Chicago in that the sewage is put into a ship canal. In Chicago our canal is a ship canal of the future, but at Manchester it is actually a ship canal, but without the constant flow of fresh water which we have in Chicago. The results, from the standpoint of prevention of nuisance, are not as successful as those in Chicago. Settling tanks were used in the early days, first as chemical precipitation and then as septic tanks. Contact beds and storm water beds have been built, since the English cities are forced by the Royal Sewerage Commission to purify the storm water before discharge. The contact beds are 40 in. deep, whereas the storm water beds are only 20 in. deep. The material is largely what is called "cinder" abroad, but probably approaching our clinker. One sludge steamer is kept busy carrying the sludge away to dump in the Irish Sea.

Another noteworthy English plant is the one at Birmingham. This was built by the Birmingham Tame and Rea Drainage Board to purify the sewage of Birmingham and the surrounding towns, and prevent a nuisance in the river Tame. In 1859, chemical precipitation was tried, being supplemented later by irrigation and sewage farming. In 1901, chemical precipitation was abandoned, and septic processes tried. In 1903, sprinkling filters were introduced, and the plant rebuilt and increased until today the installation is one of the largest in England, having upwards of 50 acres of sprinkling filters. The sand catchers and septic tanks are followed by roughing tanks, which remove the suspended matter working over from the septic tanks, before treatment on the sprinkling filters. Final settling basins of the upward flow type are used. Provision is also made

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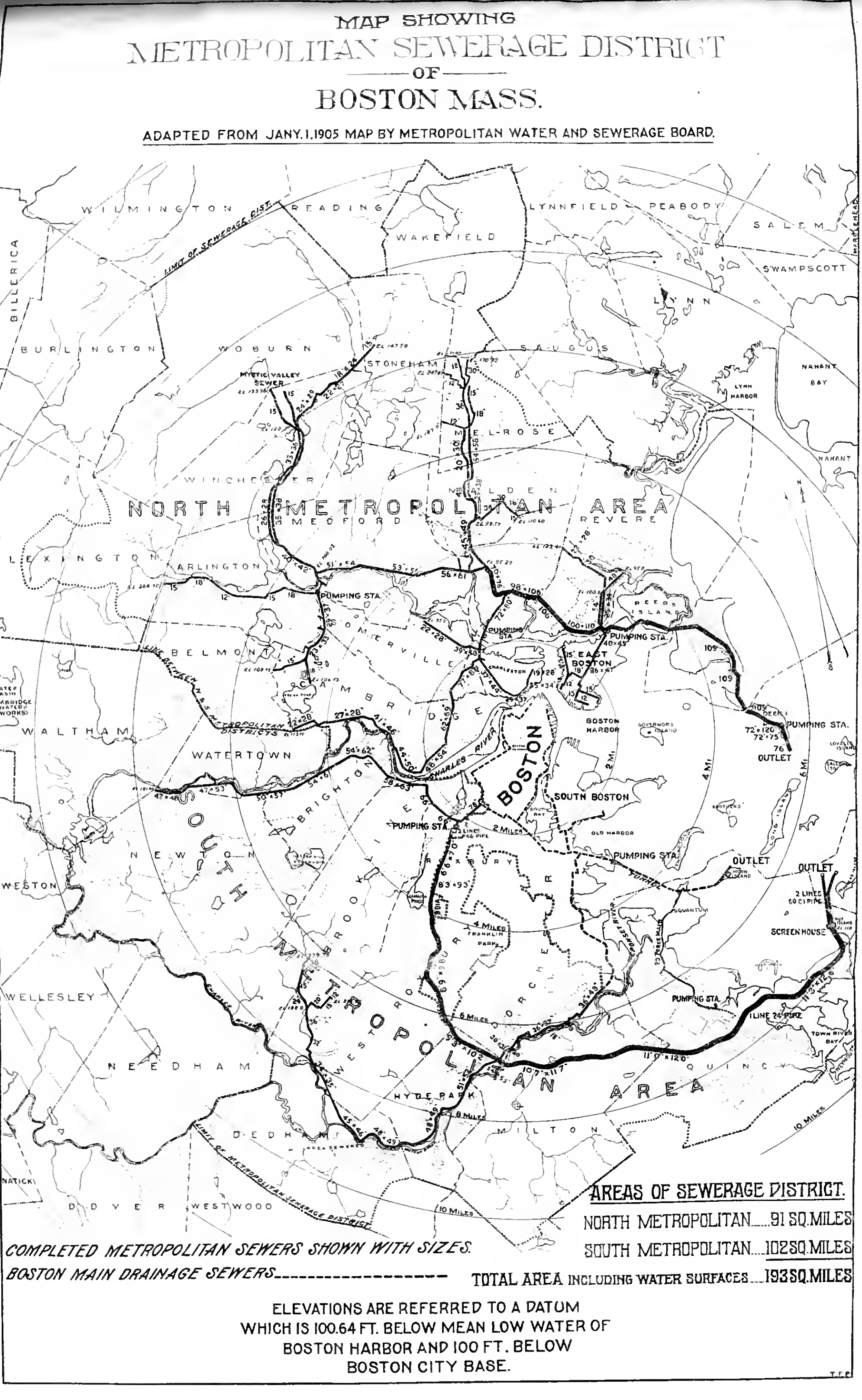

MAP SHOWING
METROPOLITAN SEWERAGE DISTRICT
OF
BOSTON MASS.

ADAPTED FROM JANY. 1. 1905 MAP BY METROPOLITAN WATER AND SEWERAGE BOARD.

AREAS OF SEWERAGE DISTRICT.

NORTH METROPOLITAN.....91 SQ. MILES
SOUTH METROPOLITAN....102 SQ. MILES
TOTAL AREA INCLUDING WATER SURFACES....193 SQ. MILES

COMPLETED METROPOLITAN SEWERS SHOWN WITH SIZES.
BOSTON MAIN DRAINAGE SEWERS------------------

ELEVATIONS ARE REFERRED TO A DATUM
WHICH IS 100.64 FT. BELOW MEAN LOW WATER OF
BOSTON HARBOR AND 100 FT. BELOW
BOSTON CITY BASE.

Fig. 2.

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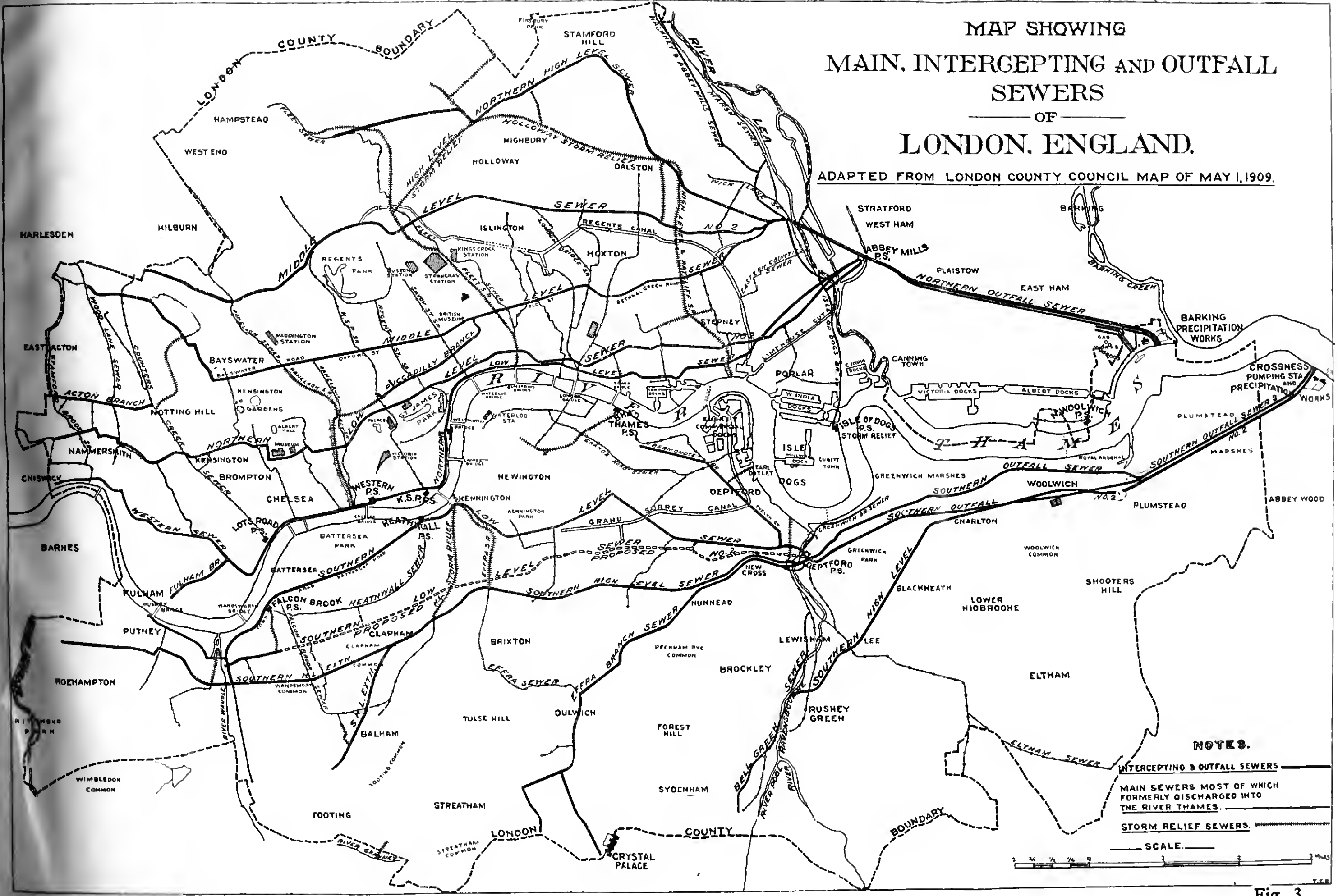

MAP SHOWING
MAIN, INTERCEPTING AND OUTFALL SEWERS
OF
LONDON, ENGLAND.
ADAPTED FROM LONDON COUNTY COUNCIL MAP OF MAY 1, 1909.

NOTES.
INTERCEPTING & OUTFALL SEWERS
MAIN SEWERS MOST OF WHICH FORMERLY DISCHARGED INTO THE RIVER THAMES.
STORM RELIEF SEWERS.
SCALE.

Fig. 3.

for handling the storm water. The plant has greatly improved the condition of the river, and its effectiveness is recognized by a judicial decision.

From England I am going to step to Germany and speak of the so-called Emscher tank and the Emscher District. The Emscher District is a sewerage district taking care of the disposal of sewage of a number of large German towns, one of which is Essen, the home of the Krupp Works. Several small water courses are available, which are sufficient for dilution if the sewage is properly treated. Many of these have been lined with concrete in order to promote a smooth flow, and some of the sewers have been built as open ditches, with neat fences on either side. To prepare sewage by the removal of suspended matter, the so-called Emscher tank was developed. The smaller tanks are circular and built of brick. They are sunk much in the same manner as well curbs are sunk in this country, a circular brick shell forming its own sheeting as the earth is excavated from the center. The larger tanks are built rectangular though usually with circular sludge wells. One of the larger plants is that at Recklinghausen (Fig. 4). There is very little odor from such a plant. This is probably due in part to the depth of the sludge well. Our experimental tank (Fig. 1) has an over-all depth of 18 ft. from the surface to the bottom of the sludge compartment, whereas in Germany they are built with

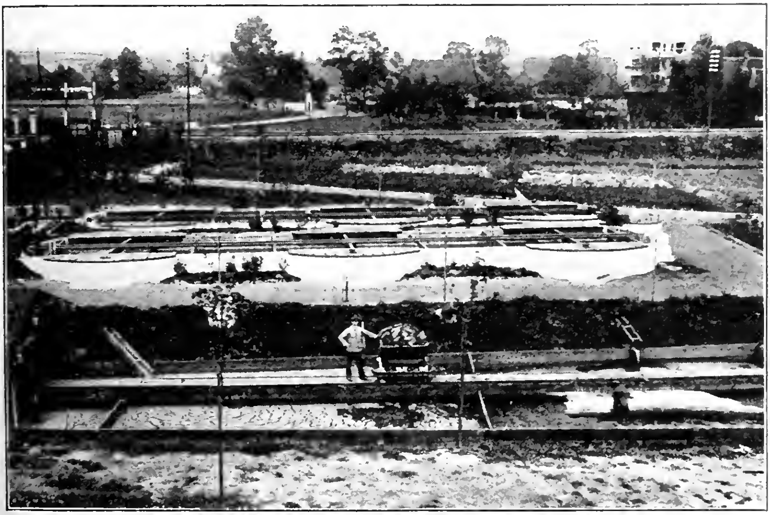


Fig. 4. Recklinghausen.
(Courtesy of Dr. K. Imhoff.)

an effective depth of 30 and 40 feet. This is important to hold back the gas that is produced by the decomposition of the sludge, and is one of the important details of such a type of treatment, because when the sludge is brought out on the sludge filter, the gas expands and honeycombs it, allowing the water to drop down. The sludge, buoyed up by the gas bubbles, rises to the surface of the water and the liquid drains away quickly. Sludge-drying beds are provided and the sludge is so handled that not over seven days are required to dry to about 50% moisture. We find that with septic sludge it takes nearly 30 days to dry to any such moisture content. There is very slight odor in the process. The material is spaded off the beds and carried away for filling. Very little is sold to farmers. The tanks have been built in closely-populated sections of the city without nuisance.

Another interesting development has occurred in Germany, namely, in the mechanical handling of fresh sludge. The Emscher tank idea is to make sludge of such character that it will dry quickly on a sludge bed. The Schaefer-ter-Meer machine has been devised in order to remove quickly by centrifugal force the moisture from sludge that is freshly settled. The sludge enters at the center of the machine and the solid matter flies out to the circumference. When the outside is filled, the machine automatically discharges the dried sludge, the inflow of wet sludge stopping for the time being. Such machines have been installed at Hanover and Frankfort, in Germany, as well as at smaller places, in connection with sedimentation basins. I understand that a machine is about to be placed at the chemical precipitation plant located at Coney Island, for New York City. It is possible in this way to take a fresh sludge and dry it very quickly to 50 or 60% moisture, so that the sedimentation basins required need not be of the size or cost that would be necessary where capacity for storage is provided, as in septic tanks or in the Emscher tank. There are no cost figures available for such a treatment under the conditions in the United States. Such a scheme would seem to be attractive if the sludge is to be burnt, as the heat content is probably higher in the fresh than in old sludge.

The development abroad of screens has been quite diverse, there being radial types, such as used in Wiesbaden; the endless-chain type where the screen travels and is cleaned by fixed brushes or combs; the fixed type of screen that is cleaned by traveling brushes or combs, as well as the familiar lifting type where the entire screen is lifted out. A new development, however, is the self-cleansing type of screen that has been installed at Reading, Pa., in connection with the sewage-disposal works there. It was invented by Mr. O. M. Weand, and consists essentially of a cylinder 6 ft. in diameter and 15 ft. long, on which is a fine screen of 40 meshes to the inch, supported by a coarse, heavy screen of ½-in. mesh. The sewage is admitted at the center of the cylinder, and drops down through the bottom. The cylinder revolves slowly and is washed from the outside by water jets, the solids being collected by an angle iron placed on the side of the screen, gradually working down to the end farthest from the inflow of sewage. With a screen of this type, it is claimed that from 15 to 20% of the suspended matter can be removed, and that it is peculiarly adaptable for the protection of the nozzles of a sprinkling-filter plant. It is, however, open to the objection of a large loss of head through the screen in a plant of any size, which would entail additional pumping unless there is plenty of gravity head available.

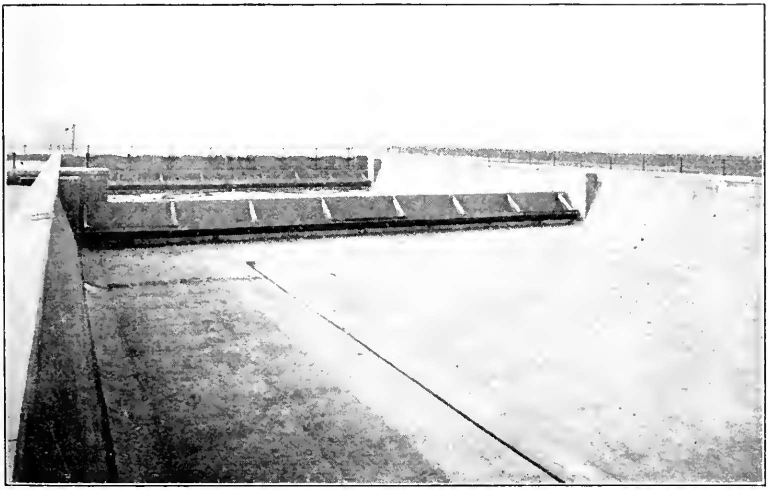


Fig. 5. Columbus, O., Secondary Tank.
(Courtesy of J. H. Gregory.)

Of the large sewage-disposal plants in this country, I shall discuss very briefly the one at Columbus, Ohio, as it is typical and was the first sprinkling filter plant of modern design to be undertaken in the United States. The sewage flows from the city proper to a pumping station by means of intercepting sewers on both sides of the Scioto river, and is pumped to a point about two miles below, where it enters the septic tanks. There are four preliminary tanks and two final tanks, so to speak. The tank was designed with the intention of having an 8-hour period, but at present it is operated with about a 16-hour period. The effluent is carried to a controlling house at the center of the beds which are arranged in radial fashion, and can be discharged on four sprinkling filters having a total area of ten acres. The nominal capacity of the plant is twenty million gallons daily, when working at the rate to yield two million gallons per acre per day. The sewage is sprinkled over the surface of the stone, trickles through, and then the effluent may be diverted to either of two shallow settling basins, which remove the suspended matter before it is discharged into the river. This settled matter is quite different in composition from the original suspended matter in the septic tanks and is much less putrescible. In Fig. 5 is shown a picture of the second, or larger, basins, which show the scum boards that were put in. During the operation of the Testing Station, no scum was noticed. Scum has occasionally formed in slight amount, but during the last summer considerable trouble occurred from suspended matter working up from the bottoms of the tanks and over onto the filters. Such action, however, scum boards will not prevent. A picture of the plant during construction is shown in Fig. 6, illustrating the arrangement of the distribution system and the method of placing the stone; the completed filter in operation is shown in Fig. 7. The low walls which divide the bed into compartments contain a tile pipe, which distributes the sewage to a cast-iron riser, at the top of which there is a circular nozzle. All the controlling apparatus of the distribution system is placed in the central house. The result of this plant has been a very distinct improvement in the condition of the river below Columbus, and the entire removal of the nuisance which used to exist.

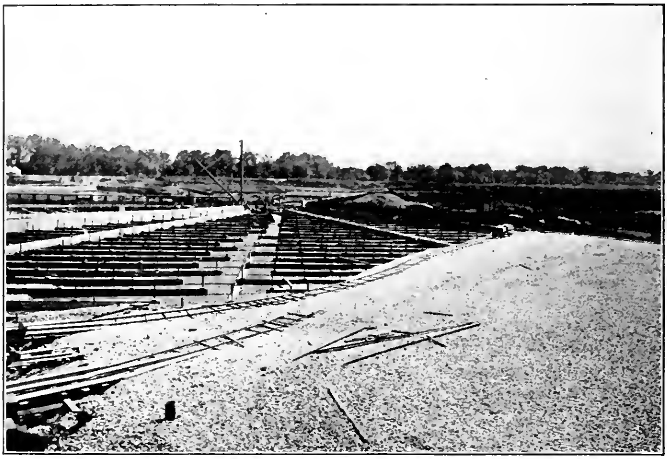


Fig. 6. Columbus, O., Sprinkling Filters, Under Construction. (Courtesy of J. H. Gregory.)

A non-putrescible effluent is produced, the purification being sufficient, since the water is not used by any city as a source of supply until after the river has entered the Ohio.

I am now going to give you a few brief notes on the experimental sewage-testing station which we are operating at 39th Street. I have shown you a typical analysis of the sewage compiled from the results of over a year. Fig. 3, of Mr. Hill's paper (in this issue of the Journal) shows the main sewerage system of the city. The drainage area tributary to the 39th Street Pumping Station is somewhat over 22 sq. miles, extending from 87th to 31st street and westerly from Lake Michigan to State Street, and as far as Ashland Avenue on the southwest corner. It is the sewage from this district which has been tested in our experimental plant. In our investigations, we have also taken samples from typical sewer outlets in the Calumet region, and are extending our survey to other sections, in order to establish the concentration and character of the sewages in the city.

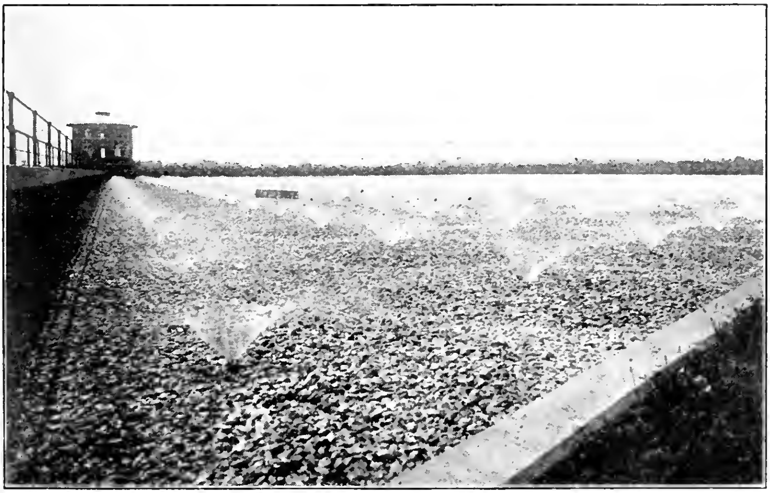
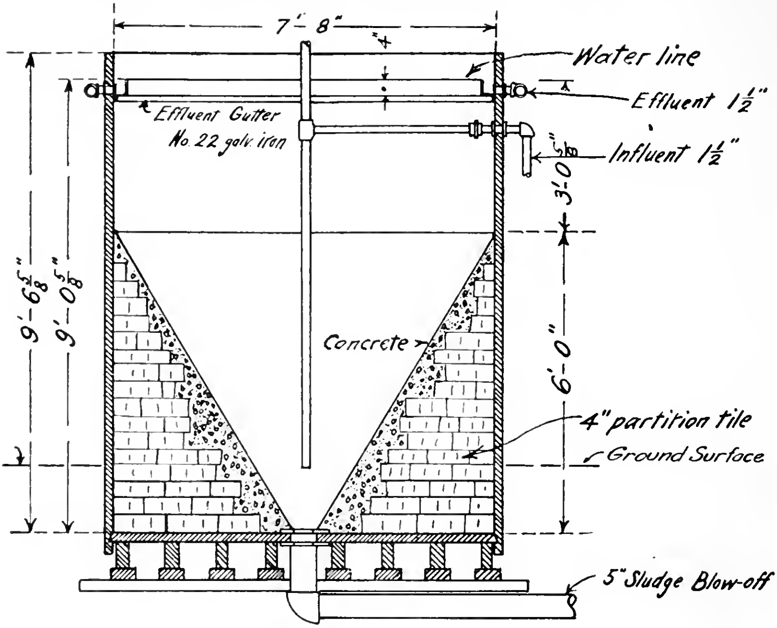
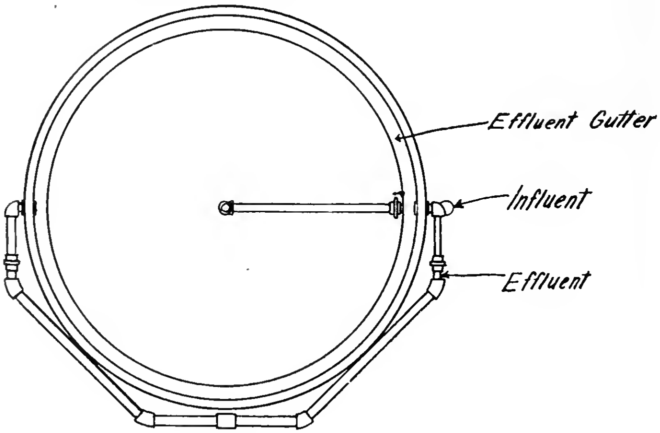


Fig. 7. Columbus, O., Sprinkling Filters.
(Courtesy of J. H. Gregory.)

The sewage is pumped up from the intercepting sewer by a 2½ in. centrifugal pump, the suction of which is protected by a screen, with bars set ⅝ in. opening in the clear. It then enters the grit chamber and is divided through three experimental tanks, two of which are septic and one a settling tank. The grit chamber also supplies a modified Dortmund tank (Fig. 9) and the Emscher tank (Fig. 1.). The amounts supplied to each device are measured, and a continuous record kept over 24 hours. The essential part of our



Sectional Elevation


Effluent Gutter
Influent
Effluent

Plan

The Sanitary District of Chicago
Sewage Disposal Investigations
Dortmund Tank

Fig. 9. Modified Dortmund Tank.

work is the study of the different means of preparatory treatment. We have been operating an open and a covered septic tank, with periods of 8 and 6 hours of nominal displacement; also, a plain sedimentation tank of 8, 6, and 4 hour periods of nominal displacement. Our Emscher tank has been operated with a period of ½, 1, 2, and 3 hours nominal displacement in the upper settling chamber, and the modified Dortmund tank is operating on about a 6-hour period.

The difference between these processes is chiefly in the relation between the sludge and the incoming liquid. In the septic tanks the sludge is allowed to lie, and is washed continuously by the incoming liquid passing over its surface. At times the liquid that discharges from the tank is worse than the crude sewage which enters it. In the sedimentation tank, the sludge is removed whenever it shows signs of septic action. In the modified Dortmund tank (called by Prof. Phelps the "biolytic" tank), all the liquid which enters the tank comes in at the bottom and rises through the entire depth of the accumulated sludge. This tank has produced almost continuously a large amount of hydrogen sulphide, and is an extremely interesting type of tank to study, because it gives a comparatively clear effluent. The Emscher tank is the direct opposite, in that the incoming liquid is kept entirely separate from the digesting solid matter.

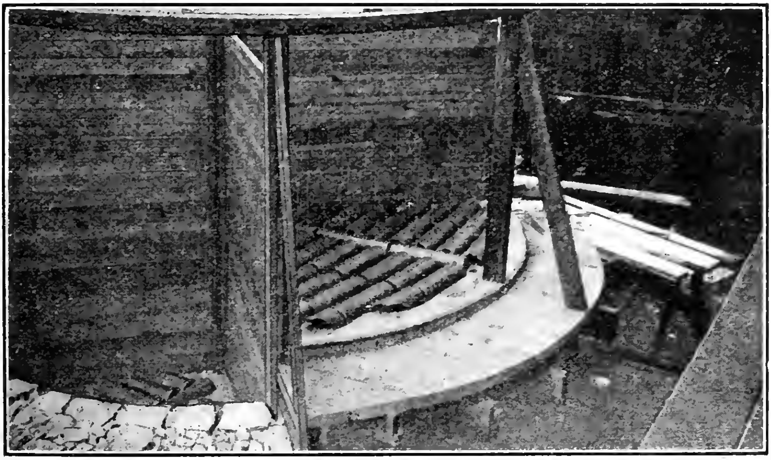


Fig. 10. Half-Tile Under Drains at Bottom of Filter.

We have also 31 distinct experiments going on in 7 sprinkling filters. We are using different sizes of stone, and depths from 4½ to 9 ft. (Fig. 10). Some of our filters are provided with settling basins, so that we can settle the sediment that is washed from the filter. We also have sludge filters on which we dry the sludge in warm weather (Fig. 11), and various apparatus for experiment, such as a dilution tank, rotary tank, and an apparatus for screening experiments. These are distinct from the routine work of the plant.

The general appearance of the plant as seen from the water front is shown by two pictures (Fig. 12 and Fig. 13), one of which illustrates our typical sprinkling-filter installation in wooden tanks 15 ft. 6 in. nominal inside diameter; the controlling house in which the effluents of the tanks are measured, and the sewage to be distributed to the sprinkling filters is also measured. We have one filter that is covered and another which is built with rubble stone sized to give freer aeration. We successfully operated our sprinkling filters all through last winter, although a small ice-cap formed as shown in the picture (Fig. 14). The distribution was much improved during last summer, so that during the present winter little ice formed.

From this brief description of the plant, you will gain an idea of our work. In the course of the next few months we expect to obtain a complete idea of what we must plan in order to extend the capacity of the canal, and take care of the growth of the city which is expected for the next ten and twenty years. We have come to the conclusion that the best possible scheme for the disposal of Chicago sewage is through the method of dilution and discharge into the Drainage Canal, because in that way we can keep all of the sewage out of the lake. In regard to the Calumet region, we have found that the cheapest method for the disposal of the sewage is to keep all the sewage out of the river by an intercepting sewer, to discharge at Blue Island into a canal from the Calumet to the Sag. This is cheaper than the purification of sewage and safer from a sanitary standpoint than the discharge of even purified sewage into the lake

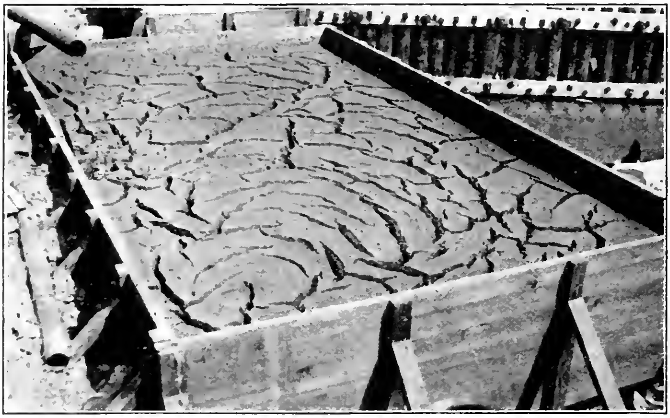


Fig. 11. Drying Sludge at 39th Street Station.

of the volume to be expected in that region, so long as the water supply of the city of Chicago is not purified. On account of the bacterial content, a sprinkling-filter effluent alone would seem hardly sufficient unless sterilized.

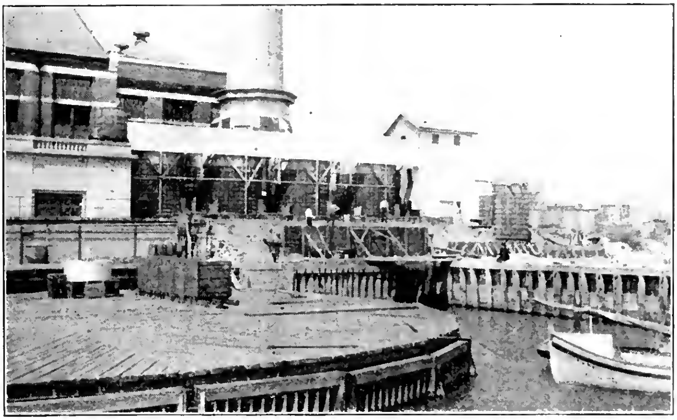


Fig. 12. 39th Street Sewage Testing Station—From the East.

In the Loop district and the more congested sections of the city, at the time of the rebuilding of the sewers necessitated by the construction of the transit tunnels, some means can be introduced for purifying the sewage before discharge into the canal. If a separate system is built, as proposed by the Superintendent of Sewers, Mr.

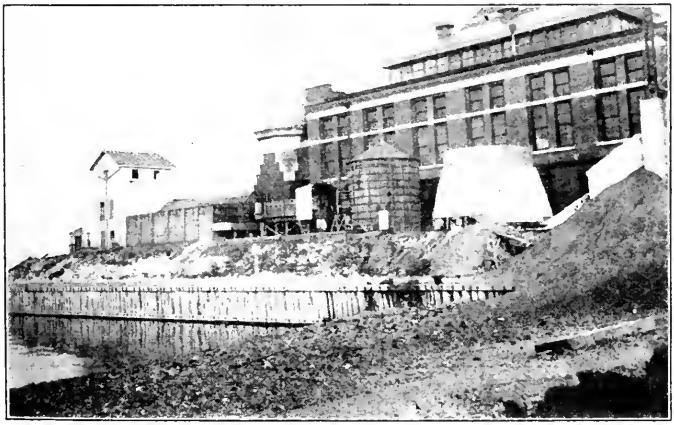


Fig. 13. 39th Street Sewage Testing Station—From the North.

C. D. Hill, a grit chamber at the outlet of the storm-water sewers would undoubtedly remove much of the grit and mineral matter from the street wash, and properly designed Emscher tanks at the outlets of the sewage system proper would lessen the amount of organic wastes which would have to be cared for by the canal. In the industrial sections of the city, settling of the wastes and other special treatments will undoubtedly become necessary in the near future, in order to prevent deposits in the river and the rapid exhaustion of the capacity of the canal.

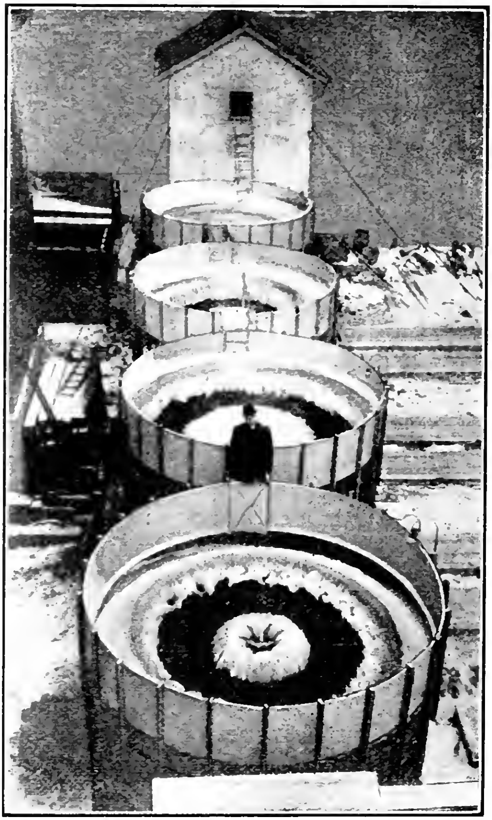


Fig. 14. Ice Caps in Winter Season.

In conclusion, I wish to acknowledge the courtesy of the Trustees of the Sanitary District of Chicago and of their Chief Engineer, Mr. George M. Wisner, in permitting the use of drawings and data in the preparation of this paper.

DISCUSSION.

W. G. Potter, M. W. S. E.: In the German plant shown, where the sewage was passed through the screens only, to the rivers, is the water used below for water supply?

Mr. Pearse: In general, it is not. But the German custom is, as a rule, to purify all surface supplies used for water consumption. In the case of Dresden, I think the water is not used below. Probably the best illustration of that is the Elbe at Hamburg. Hamburg purifies its sewage by screens and discharges into the Elbe. Altona is below Hamburg, and uses sand filters to filter the water supply; Hamburg also has water filters. That is, the intention abroad is that all surface supplies shall be filtered, but the tendency has been toward the use of ground-water supplies wherever they can be had, in order to avoid any possible pollution that might pass the filter.

Mr. Potter: Does the screening only of the sewage necessitate more purification than is ordinarily given the water in the filters? Would that process be more expensive?

Mr. Pearse: The object of the screening is largely to remove the floating matter and a certain amount of the coarse suspended matter. Sufficient dilution must be had. The pollution there may be great and the bacterial content large. The saving to the water works, however, would not be very great, if any, because the removal of bacterial matter is practically nil. That is, the use of sewage screens is practically restricted to questions of nuisance, and is not applicable to questions of water purification.

B. J. Ashley, M. W. S. E.: I would ask Mr. Pearse if he has made any experiments along the line of inducing gentle currents of air through the filters and noting whether the degree of purification is different from that in which there is no induction of air through the filters?

Mr. Pearse: No, we have not made such experiments, because in the winter time it would not be practicable unless the air were heated, and would involve expense; in the summer time we have not a very good chance on account of the sheltered conditions. We are thinking of putting in a little blower and trying it, but there are three or four months of the winter when we are liable to have air at freezing temperatures.

Mr. Ashley: Induced or enforced aeration of filter beds has been tried in Germany and has been alluded to in some of the articles recently published in this country. I am sure Mr. Pearse has read of this introduction of air into modern filter beds and found that method to very materially increase nitrification. Mr. Hering, of New York, visited Germany last fall and during his investigations of the Emscher tank he also investigated some experiments that had been recently made regarding the aeration of beds, by using revolving cowls on the top of air stacks which connected with the subdrains. When the wind blew, a current of air was forced very gently down the ventilating shafts and into the bed at the bottom, the result being, as stated, that nitrification was said to be doubled. Mr. Hering has introduced this feature, I believe, into the Atlanta, Ga., plant. I have recently reviewed an article that appeared in the *Engineering Record* a year or two ago relative to the experimental sewage-disposal plant that was built at Philadelphia, and in order to arrive at some determination in regard to the effectiveness of introducing air into the beds, they attached the air ducts that were connected to the collecting drains to the chimney stack in order to induce currents of air into the bed.

In connection with this, I may say that on Saturday I received a letter from a gentleman in Michigan regarding the operation of an open filter bed in that state which I designed some three years ago, to the collecting drains of which I attached a chimney some 20 ft. in height. His remarks in substance were that in frosty weather he and his workmen have frequently seen condensation in the form of white vapor from the warm draughts of air passing out of the chimney, having the appearance of smoke coming from a furnace or stove, the vapor being quite white.

This seems to show the effectiveness of even a chimney 20 ft. high in drawing the air down through the filter bed during the winter season and discharging it at the top of a chimney. So that, during winter or summer, induced aeration in filter beds must have a decidedly beneficial effect. If Mr. Pearse could make some experiments along that line, I am sure many of us would be much interested to know the results, and to know that such experiments could be made in this country as well as abroad.

APPENDIX.

NOTES ON SEWERAGE SYSTEMS AND SEWAGE DISPOSAL.

Boston and Suburbs, served by Boston Main Drainage Works and the Metropolitan Sewerage System.

Metropolitan Sewerage System:

Area served: 191.37 sq. mi.
Population: Est. 1909, 873,577.
Miles of intercepting sewer: 101.99.
Outlets (2):
North Metropolitan System, at Deer Island, into Boston Harbor, 90.5 sq. mi.
South Metropolitan System, at Quincy, into Boston Harbor, 100.87 sq. mi.
Pumping Stations:
Metropolitan System—6 avg. daily cap. 3.4, 4.2, 22.7, 32.1, 58.6 and 60.6 million gals. respectively.

Cost:	
North Metropolitan, to Dec. 31, 1909	$6,312,130.61
South Metropolitan, to Dec. 31, 1909	8,785,297.80
Maintenance Cost:	
North Metropolitan, 1909	141,387.71
South Metropolitan, 1909	97,279.56

References:
Annual Report—Metropolitan Water and Sewerage Board, 1909.

SEWAGE FARMS AT BERLIN.

Population (1908): 2,137,034.
Area City of Berlin: 25 sq. mi. = 16,000 acres.
Area Sewage Farms: Total = 43,100 acres.
Underdrained and farmed = 23,250 acres.
Amount of sewage handled:
Total, 73 million gals. per 24 hrs. (1908).
Per capita: 35 gals. (from 20 to 102 gals. per day.)
Cost:
Sewerage System in City (651 mi.) and 12 pumping stations (6,000 h. p.) about............................$23,593,000.00
Sewage farms, underdrainage, buildings, etc., about....... 16,250,000.00
Net Income from Sewage Farms (1909)..................... 125,000.00
(Leased land, sale of garden truck and cattle).
Reference: Pamphlet folder issued by City of Berlin, 1910.

LONDON.

Population (1908): 7,323,327.
Area tributary: About 140 sq. mi.
Flow of Sewage (1908): Total dry weather flow, 340 million gals. daily.
Maximum Storm Flow: 1,210 million gals. daily.
Length of main, intercepting and storm water sewers: 352 miles.
Pumping Stations:
Number: Storm water (6), dry weather flow 5, total 11.
Capacity: Total, 1,392 million gals. daily.
Horsepower total: 9,000 to 11,000.
Motive power: Steam, (6); gas, (5).
Men employed: 900 to 1,000.
Chemicals used: Grains per gallon: Sulphate of Iron, 0.8. Lime, 3.3.
Disposal Works:
Barking:
Precipitation basins (covered), 13; 860 to 1,200 ft. long by 30 ft. wide, by 8 ft. deep. Capacity: Total, 25 million gals.
Sludge Storage Tanks.
Crossness:
Precipitation basins (covered):
Six; (4), 560 ft. long by 128 ft. wide; (2), 558 ft. long by 99 ft. wide.
Capacity: Total, 26 million gals.
Sludge storage tanks.
Sludge steamers: 6. Capacity each, 1,000 long tons sludge.
Sludge produced per year (1908), 2,583,000 tons.
Total Cost to date (March 31, 1909): $55,000,000.00.
Annual Cost of operation (1907):
Disposal works, and outfalls:
Precipitation plants $242,700
Sludge handling on land.................................... 139,600
Sludge Disposal at sea..................................... 191,700
Reference: Main Drainage of London, 1909. A report to the London County Council by Chief Engineer, Maurice Fitzmaurice.

MANCHESTER.

Population (1908): About 650,000.
Area of city: 21.3 sq. mi.
Combined system.
Discharge into Manchester Ship Canal.
Amount treated daily:
Dry Flow, total, about 29 million gals.
Per capita, about 51 gals.
Storm Flow up to 151 million gals.

Works, about 5 miles from City proper.
  Capacity daily, 151 million gals.
  Sand catchers with chain bucket dredgers.
  Screens:
    Coarse: 6 in. openings.
    Medium: 1¼ in. openings.
    Fine, ½ in. openings.
  Septic Tanks: 12. Total capacity, 12 million gals.
  Storm Water Tanks: (Open.) 4. Total capacity, 5½ million gals.
  Contact beds. Furnace clinker, screened.
    Primary, 92. Total area, 46 acres. Depth: 40 in.
    Secondary, 31 in operation. Total area: 15.5 acres. Depth: 40 in.
  Storm water filters: Furnace clinker, unscreened.
  Beds. Total area: 27 acres. Depth: 30 in.
  Sludge:
    Sludge steamer (1). Capacity, 1,000 long tons.
    Amount removed yearly, 250,000 tons.

Cost of works to date, about	$3,400,000
Total Annual Cost	150,000
Including cost of sludge disposal	43,000

References: Annual Reports. Rivers Department, 1909, 1910. City of Manchester.

BIRMINGHAM, TAME AND REA DISTRICT DRAINAGE BOARD.

Population (1910 estimated): 954,533.

Area served (City, 3 boroughs, 4 urban districts, 1 rural district): 94 sq. mi.

Combined system.

Discharge into River Tame.

Amount treated daily:
  Dry Flow Total, 33 million gallons.
  (1908) Trade Waste, 5.8 million gallons.
    Per capita, 36 gallons.
  Storm flow up to six times dry weather flow.
Boards own 2,830 acres of land.
Works: At Saltley, Cole Valley and Minworth.
  Saltley:
    Sand catcher, cleaned by mechanical dredger.
    Septic tanks, 20. Total capacity, 8.7 million gallons. Depth, 5 to 7 ft.
      Normal period, 21 hours.
      Sludge pumped out onto land. Buried in trenches.
    Roughing tanks, 5. Total capacity, 6.7 million gallons.
  Minworth—(Fed by 8 ft. conduit 5 mi. long from Saltley):
    Silt Tanks:
      22 in all. 2 units of 8 each, 25x25 ft. by 20 ft. deep.
      6 tanks each, 44 ft. diam. by 33½ ft. deep.
    Sprinkling Filters:
      Area: 50 acres (1909).
      Depth about 6 ft.
      Rate of application about 960,000 gals. per acre per day.
      Stone 1 to 2 inches.
    Settling Basins: Upward flow type.
    Storm Water Beds: 30 acres.
      5 ft. graded coke breeze on coarse underdrains.
Capital Cost:

Works	$4,650,000
Land	2,190,000

Reference: J. D. Watson. Birmingham Sewage Disposal Works. **Inst. C. E.** 1909-1910.

EMSCHERGENOSSENSCHAFT.

Regulates and constructs sewerage systems.
Constructs and operates sewage-purification plants.
Regulates drainage and streams of entire valley.
Composed of 100 Kreis (corresponding to American "County").
Area: 308 sq. mi.
Population: About 2,000,000.

Estimated cost of works	$12,000,000
Of this, sewerage and disposal works	4,000,000
Disposal works	1,200,000

Type of Disposal Works:
- Screens.
- Grit chambers.
- Emscher tanks.
- Sludge drying beds.

References: Saville. The Emschergenossenschaft and the Imhoff tank. Eng. News, Dec. 1, 1910.

COLUMBUS, OHIO.

Population: About 180,000.
Area in corporate limits: 16.81 sq. mi.
Sewage pumped and treated: 11.9 million gals. daily average (1909).
Capacity of plant: 20 million gallons daily.
Septic tanks: 12 ft. deep.
- Primary. 4. Each 56 ft. 6 in. by 150 ft. long, capacity 710,000 gals.
- Secondary. 2. Each 115 ft. 6 in. by 262 ft. long, capacity, 2,590,000 gals.
- Total capacity: 8.02 million gallons.

Gate house containing valves for controlling the operation of filters.
Sprinkling filters. Radial from gate house.
- Area: 10 acres—divided into 4 beds, 2½ acres each.
- Stone. Depth averages 5 ft. 4 in.
  - Size of major portion 1 to 3 in.
  - Lower 10 in: 3 to 4 in.
- Designed to yield 2 million gallons per acre per day.

Settling Basins:
- 2. Each of capacity 2 million gallons.
- Depth averages 4 to 4½ ft. deep.

Sludge is blown into river from septic tanks.

Sludge is pumped into river from settling basins.

Cost: Sewage Purification Works complete, $456,350.

Note: The total cost of the improved sewage works, including pumping stations, force mains, levees, railroad bridges, purification works, etc., was $1,351,020.

Reference: John H. Gregory. The Improved Water and Sewage Works of Columbus, O. Trans. Am. Soc. C. E., Vol. LXVII, p. 206 *et seq.*

EXPERIMENTAL COAL MINE OF UNITED STATES BUREAU OF MINES*

George S. Rice, M. W. S. E.

Presented April 12, 1911.

The explosibility of coal dust in air having been successfully demonstrated in the 100 ft. gallery of the United States Bureau of Mines at Pittsburg, and in the longer galleries at Lièvin, France, and Altofts, England, the next step in the investigation of coal dust explosions by each of the experiment stations was to determine the exact conditions under which such explosions took place. When these conditions were understood, tests of various preventative measures could be undertaken with some degree of precision. Prevention, or at least limitation, of explosions in mines was, of course, the real objective of the stations.

The gallery at Lièvin, a short length of which was erected in 1908, was gradually lengthened to a distance of 990 ft., and an increase to 1500 ft. is under contemplation. The gallery at Altofts, also erected in 1908, was about 950 ft. long as originally laid out. In both these galleries the limitation of strength prevents safe loading with pure coal dust for more than a distance of 400 to 500 ft.; on loading beyond this distance the galleries are sometimes ruptured. The managements of these stations have expressed the desirability of making tests of coal dust in longer and stronger galleries, since it is impossible to solve all the problems surrounding an explosive wave in the short distances now available; moreover, methods of limiting an explosion which were successful with a loading of coal dust for a length of 300 or 400 ft., would probably not be so with a longer loading or a larger explosion.

The Director of the Bureau of Mines, Dr. J. A. Holmes, and his technical staff, at an early date appreciated these unavoidable limitations of a surface gallery, and hence desired to obtain an underground gallery or mine opening, which would not only enable the tests to be made on a larger scale than is possible in external galleries, but in which experiments could be made under actual mining conditions. In such an underground gallery there would be no restriction as to the extent and violence resulting from explosion experiments, provided a suitable location was secured. Moreover, the methods of limiting and preventing explosions—the real objective of all such investigative work—could be tried under real mining conditions.

It was foreseen that the greatest difficulties in experimenting in an underground gallery would be,

(1) To obtain certain desired natural conditions.

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*This paper was prepared for the Western Society of Engineers by permission of the Director of the Bureau of Mines.

(2) Having obtained those conditions, to carry out and control the experiments in a scientific way, and be able to get complete records in the face of violent explosions.

After a long search a location for the experimental gallery, or mine, has been selected near Bruceton, Pa.

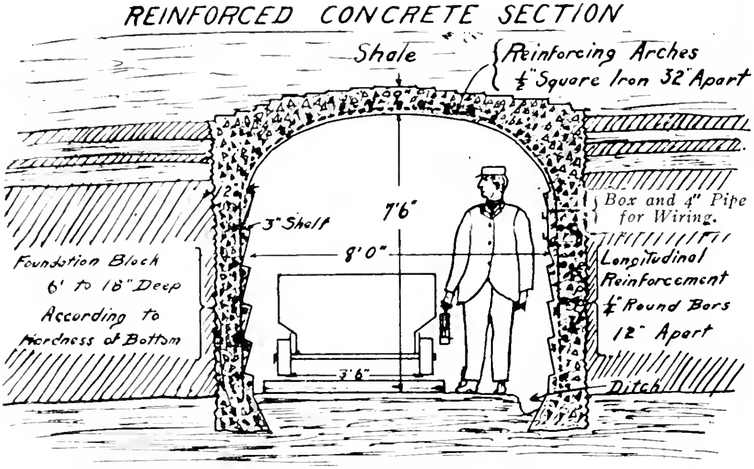
From 2500 to 3000 ft. of straight entry can be driven from the outcrop in the Pittsburg seam. In the past in certain mines operating in the seam great explosions have occurred.

The thickness of the seam at the experimental mine is from 5 to 5½ ft. of practically clean coal, with a few streaks only, of shale and sulphur (pyrite). Above is a "draw-slate" 6 to 12 inches thick, over which there is an impure and irregular "roof coal" from 1½ to 2 ft. in thickness.

Entrance to the Experimental Mine near Bruceton, Pa.
(before lining with concrete.)

The entries will probably be either level or slightly rising, except for irregularities, so that there will be no serious problem of drainage. The entries enter from a steep sidehill and a cover of from 60 to 160 ft. is obtained. The openings are well located with reference to explosion effects, as there are no houses in the vicinity, except those in connection with the plant. The mine is fairly close to a railroad (one-third mile) so that the coal dug in advancing the entries can be loaded on railroad cars. By damming a ravine close at hand, water can be obtained for a boiler plant and fire protection. Natural gas for experimental purposes and for use in a gas incline engine and fan engine is obtained from a pipe line which passes a few hundred feet from the mouth of the mine. Finally, the situation is near enough to Pittsburg to allow convenient movement of the engineers and physicists between the Testing Station there and the mine. The location of the mine is twelve miles southwest of Pittsburg on the Wheeling Division of the B. & O. R. R. The coal and necessary surface surrounding the mouth of the mine has been obtained at a nominal rental from the Pittsburg Coal Company.

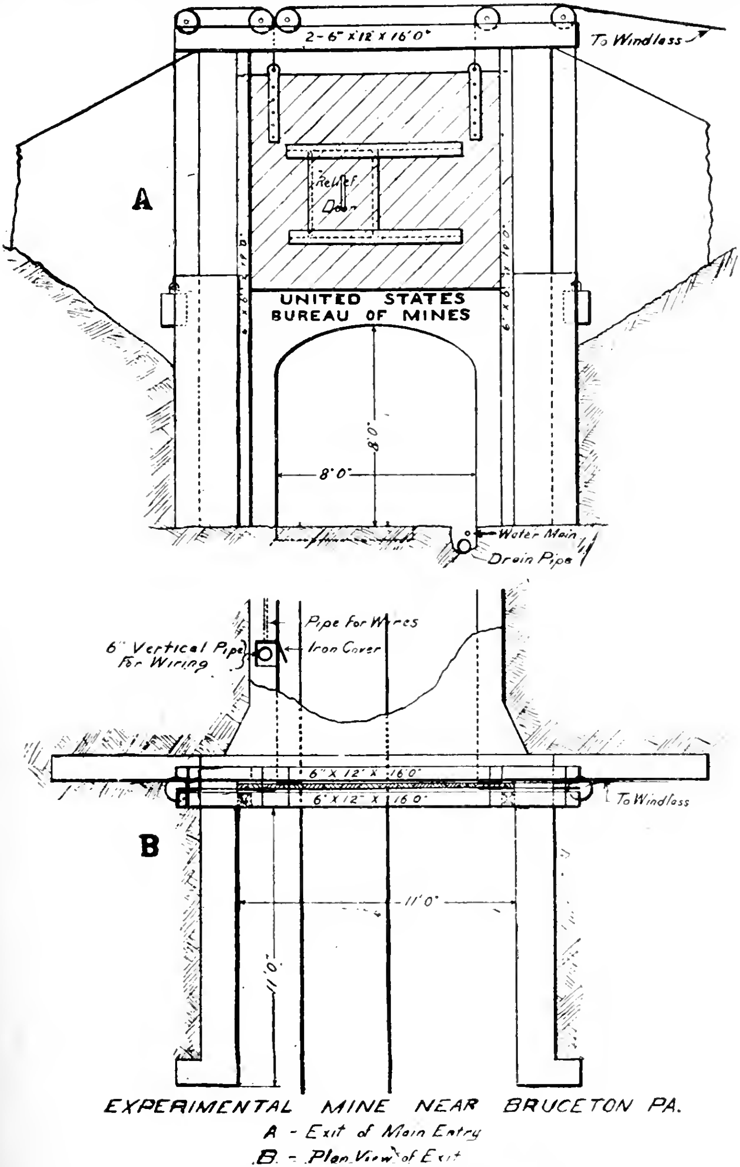
Progress and Development.—After a long continued search for the best location which would give the desired conditions, the present site was selected, and about the middle of December permission was obtained from the Secretary of the Interior and the Director to proceed with the laying out of the mine. The surveys having already been made, the outcrop was uncovered and two parallel entries, with 40 ft. of pillar between them, were started. At the time of writing this description (March 16, 1911) these entries have been driven in under cover over 200 ft.



Reinforced Concrete Lining.

The right hand entry, which will be considered the main one, was started in the lower part of the coal seam, taking the top of the limestone, which is 5 ft. below the coal seam, as a floor. Between the limestone and the coal seam there was at this point a hard clay; the entry was excavated in this and in 3 ft. of the lower part of the coal seam, leaving about 2½ ft. of the main seam for a roof.

After going in about 50 ft. in this manner, the floor was gradually raised on an upgrade until the excavation was wholly in the coal seam and the draw slate above it. The so-called draw slate is a soft shale or clay which comes down immediately on mining the coal. Above it, as is generally the case in the Pittsburg seam in this district, there is 1½ to 2 ft. of so-called roof coal which is generally of poor quality and interspersed with layers of shale.



Proposed Concrete Entrance to Mine.

The parallel entry, which will be called the air course, was driven wholly in the coal seam. It is not intended to use the mouth of this entry in explosion tests. For normal driving this air course will be the return, and ventilation will be obtained by a small fan driven by a gas engine located at the top of a small upcast shaft near the mouth of the air course. This shaft will be offset from the air course about 6 ft.

There will be another entrance to this air course, joining at about 110 ft. from the mouth, which will enter at an angle of about 55° on the opposite side from the main entry. At the mouth of this side approach there will be placed a short length of concrete gallery with explosion doors, and beyond that a round steel gallery 120 ft. long, 20 ft. of which will consist of removable sections that can be rolled out of the way when it is desired to isolate the 100-ft. gallery. This part will then be identical with the 100-ft. steel gallery at the Pittsburg station, with one exception,—a branch off of it a short distance from the inlet to which a large reversible fan will be connected. The object of having this steel gallery, which is 6 ft. 4 in. in diameter, separable from the mine is so that experiments similar to those conducted at Pittsburg can be made. The gallery at Pittsburg is so continuously occupied with the testing of explosives that systematic testing of coal dust cannot be undertaken in it. When the removable sections before mentioned have been rolled to one side and a steel door lowered in place to cover the connection into the air course, experiments can be conducted in the isolated gallery without interfering with operations in the mine.

Dust Tests in Mine.—At the start it is intended that coal dust explosions will be originated in the steel gallery and the explosion will enter the air course through the branch, pass up the branch to the last open crosscut, then through the latter into the main entry and out of the mouth of it. The crosscuts will be driven on a circle tangent to the entries. This will require one 45° turn and one semicircular turn of the explosion wave, a condition which seems to cause no obstacle in a real mine explosion, nor does it cause difficulty in the Altofts gallery. The records of experiments in that gallery show that on the return side,—that is, towards the exhaust fan,—the dust, carried by the air current and the advance compression wave of the explosion, has been inflamed and the flame has passed around a number or all of the five right-angled turns in that gallery.

The purpose of this method of initiating explosions in the outside gallery of the experimental mine is to proceed from the known conditions in the gallery (as developed at the Pittsburg gallery) to the unknown conditions prevailing in mine entries. There is also another object, that while entries are being driven it will give double the length of travel for the explosive wave and thus allow the testing of the mathematical instruments, before the final explosion experiments which may be originated in the interior of the mine.

Fire Damp.—Besides making investigations of the explosibility of coal dust in pure air, it is intended to make tests with small percentages of methane in the air. It is generally recognized that a very slight amount of methane, even as low as ½%, may increase the chance of ignition of coal dust and more widely extend an explosion that has once been started.

The location of the experimental mine fortunately has a natural gas pipe line near it. This line takes gas from some gas wells in the same ravine. It is intended to take a branch from this gas main for use in a gas engine hoist and in a gas engine for driving a small ventilating fan. It will also be used for the purpose above indicated, of introducing when desired small quantities of gas into the mine.

Natural gas has very nearly the same composition as the marsh gas of the coal seams, the difference being that in addition to the methane (CH_4) there is from 10 to 15% of ethane (C_2H_6). This slightly varies the proportion of the mixture of air for its combustion, but the difference for practical purposes is negligible.*

The gas will be piped to certain points, and by a system of mixing with the ventilating current will be carried through in whatever proportions may be required; approximate percentages will be determined through meter measurements, and precise determinations made by sampling the air and gas mixture and analyzing. It is considered that this line of investigation of the effect of small percentages of methane is most important, and the need for it has been expressed by foreign critics of coal dust experimentation now being carried on.

Concrete Lining.—It is anticipated that great explosive force will be developed at the mouth of the main gallery; hence it is intended that the timbering which is now in place must be supported by reinforced concrete walls and arching. The latter will present a smooth surface to the explosive wave and thus prevent great falls at the mouth of the mine, the occurrence of which would lead to heavy expense and delay in clearing up after each experiment.

It is the plan to concrete the approach leading from the steel gallery to the air course, and it may become necessary to concrete between this connection to the mouth of the air course, although it is not intended to load that portion of the air course with coal dust. It is expected that the explosion wave entering from the gallery entrance will not have gained sufficient momentum at the junction with the air course to break down doors or stoppings erected between that point and the mouth of the air course, but will be deflected into the air course toward the face.

Method of Driving Entries.—The method of driving entries

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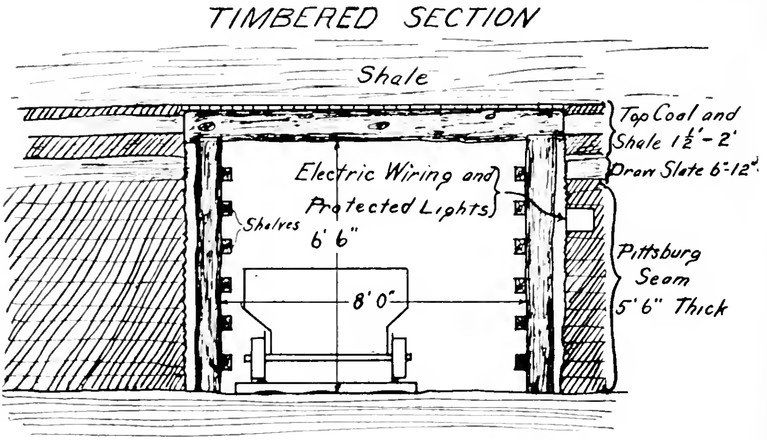
*See digression on dangers from gas wells given at end of paper.

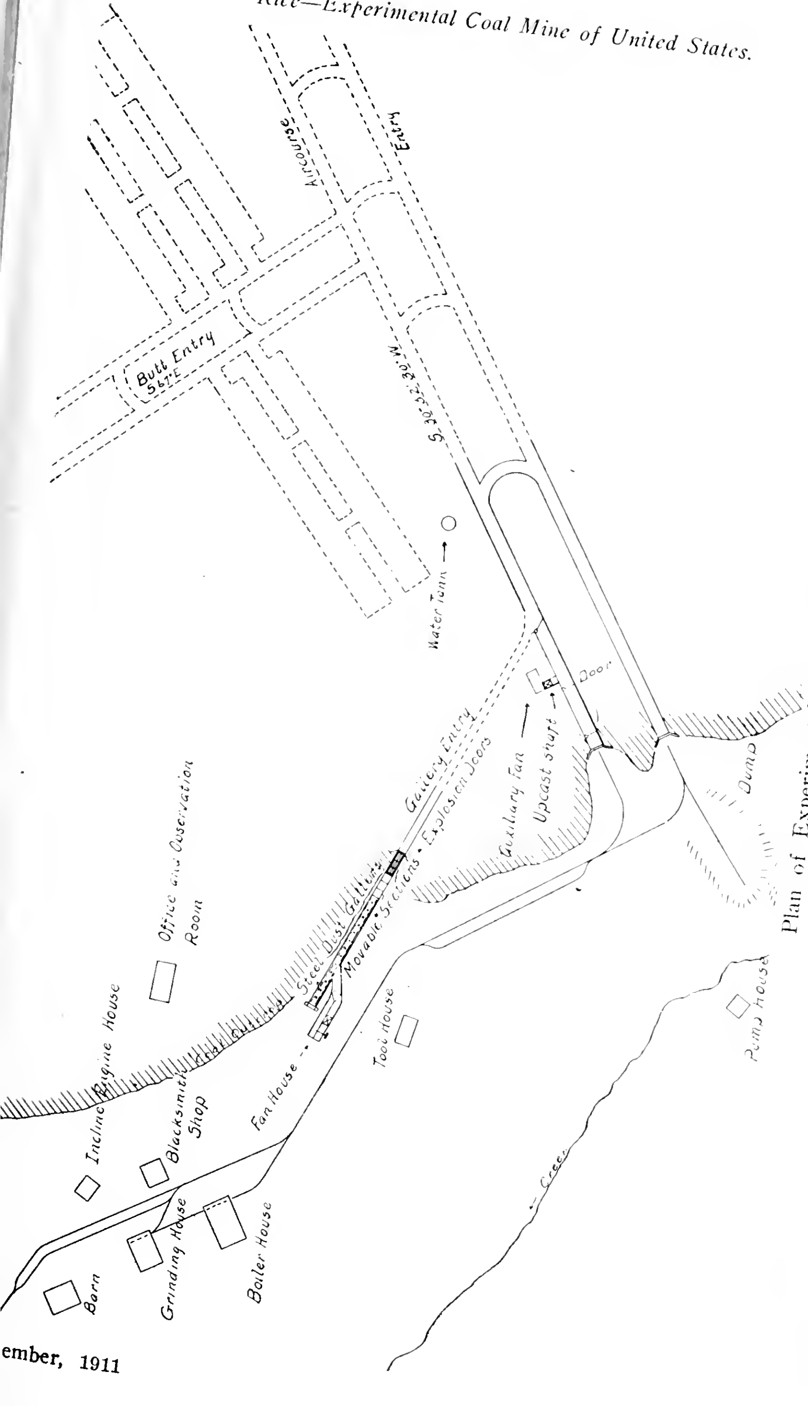
is the usual one employed in the Pittsburg coal seam. The coal is undercut and shot down with explosives, which in this case are of the "permissible" type, electrically fired. The coal is loaded on pit-cars, which are hauled by mules to the mouth of the mine, thence over an outside tramway with slight descending grade, to the head of a rope incline. Trips of cars are lowered, by the hoist under brake, to a trestle and tipple located on a siding of the B. & O. R. R.

Buildings and Apparatus.—It is necessary to have a considerable number of buildings; these are now under construction. There will be a boiler house with boiler to furnish steam for the several engines, including the fan engine. A crusher and grinder house will be necessary to grind up the dust for the experiments; as much as four tons will be necessary when the mine is fully developed. There will be a blacksmith shop containing a small equipment for the necessary repairs and an engine house for the incline engine. There will be a combined office and observation room for observations and the starting of explosions, in connection with which there will be a small laboratory for field analyses of gas and mine air samples. Several small buildings, including a barn for the mules, have already been constructed.


TIMBERED SECTION
Shale
Top Coal and Shale 1½'-2'
Draw Slate 6"-12"
Electric Wiring and Protected Lights
Shelves
6' 6"
8' 0"
Pittsburg Seam 5' 6" Thick

Timbered Lining of Mine.

Ventilating Fan.—The ventilating fan for the experiments must be of such size as to create all the conditions which may surround an explosion in a mine. It is desirable to obtain high velocity in restricted areas, say 1500 ft. per minute, over a considerable distance. A capacity of 80,000 cu. ft. per minute at a pressure of 2 in. water gauge and 15,000 cu. ft. per minute at a pressure of 6 in. water gauge, is specified and has been guaran-



Plan of Experimental Coal Mine.

teed by the builders. The fan is made reversible so that experiments may be conducted with dust explosions going against the air current as well as dust explosions going with the air current. The Altofts gallery fan is not reversible and the explosion portion of the gallery is at the intake end.

Pressure and Recording Instruments.—The important objectives of the experiments are to obtain the speed of the explosion as indicated both by pressure and by flame; the variation in pressures at different points along the course of the explosion; the temperatures; and the samples of the gases immediately preceding the inflammation of the dust or gas and immediately following the inflammation at a given point. Such experiments will require apparatus of an extremely sensitive nature.

A similar set to that used in the Altofts gallery has been purchased from the Cambridge Scientific Instrument Company of England. These were designed primarily for external galleries, but it is believed there will be no serious difficulty in arranging them in steel plate boxes sunk into the coal rib. It may be found necessary to design new and additional apparatus.

An important point in the use of the recording instruments is their driving, also the making and breaking of electric circuits. To connect these instruments with the outside will require the wiring to be done in such a way that it will not be torn out by the explosions. It is proposed to place the wiring in pipes arranged in a groove in the coal rib and at the mouth of the mine; these pipes will be set in concrete but arranged with suitable boxes at short distances apart so that the wires may be gotten at.

It is evident that to make the apparatus safe under the enormous pressures which are expected, which may run up to 500 pounds or more per square inch, will need great care. To obtain the currents for the instruments will require a very steady running generator engine set. It is expected to obtain a set which will be sufficiently large to allow some lighting with incandescent lamps in and around the mine.

Limiting or Preventing Explosions.—The real importance of the experiments is not the mere study of explosion waves, although of great scientific interest, but to study methods for preventing or limiting explosions. It is, therefore, proposed to experiment with all the important methods that have been suggested up to date as described in U. S. G. S. Bulletin 425 and Bureau of Mines Circular No. 3, among which may be briefly recited, watering by water sprays, by exhaust steam sprays, and by deliquescent salts (calcium chloride); also by the use of rock and shale dust in various ways. It is believed that these experiments, if tried in a mine on a sufficiently large scale, can effectually demonstrate the relative efficiency of the various methods.

Explosives.—A secondary purpose of the experimental mine, and by no means an unimportant one, is the study of explosives which have been placed on the permissible list for use in gaseous and dusty coal mines—testing them under actual working conditions in coal.

Dust Production.—Another purpose to which the experimental mine can be put is in studying the relative production of inflammable dust by different types of machines which undercut or shear the coal.

Gasoline Locomotives.—Still another purpose is the testing, under mine conditions, of gasoline motors to determine the safety of the apparatus in actual use, and the degree to which the air may be vitiated by the exhaust gases.

Electrical Devices.—It is probable that many electrical mining devices can be tested under actual service, together with tests of insulation of mine cables.

Concrete, also Steel Timbers and Props.—The growing scarcity of mine timbers, as well as the danger of fire from their use, suggests the importance of testing reinforced concrete timbers and ties; also steel props and ties in the experimental mine.

The relative advantages of brick arching and reinforced concrete for lining the main entries can also be studied, and under severe conditions.

It is probable that the equipment will be sufficiently installed by the first of July to try some preliminary experiments. In the meantime the entries are being driven as fast as possible. On May 23 the main entries had been driven in over 500 ft. from the outcrop.

DISCUSSION.

H. H. Stock, M. W. S. E. (Chairman): Some of you may not be familiar with the excellent work that has been started and is being carried on in Pittsburg, but those who have visited that city and have seen what has been started there, feel that a new era in mining, and especially in coal mining, has begun. Thus far the work has been largely on a laboratory scale, and it has been the idea of those connected with it,—and Mr. Rice in particular, who has been a very integral and important part of the work,—to try out on a large scale what they have demonstrated on a laboratory scale.

Mr. Rice: Referring to the proposed tests in the experimental mine, of dust in the presence of inflammable gas, I will mention a very interesting case that has recently come to the Bureau, from its possible bearing on a similar problem in Illinois. In the natural gas of the Appalachian district, while 85 to 90% of it is methane (CH_4), it also contains from 10 to 15% ethane. On the other hand, ethane is not found in mine gas. This feature enabled the Bureau of Mines to determine, in certain mines of West Virginia, that there had been leakage from a gas well into the mine. The development of gas wells in coal-mine districts is a serious problem for the miner; it is going to be even worse in the future than it has been in the past, from the widening of the territory in which gas and oil is being drilled for. I have not been informed as to the new mine laws of Illinois, and do not know whether they cover the protection of mines from leaky oil and gas wells. Possibly Professor Stoek can tell us.

Professor Stoek: The new mine laws do cover that feature to some extent.

Mr. Rice: The unmined tracts of coal in southwestern Pennsylvania, and in northern West Virginia, have been very much probed for gas, and the gas wells are very widely distributed. Unfortunately many of the abandoned wells are unchartered. Some of them do not make a great quantity of gas but enough to make the situation very serious if leakage occurs into a mine. There have been a number of cases where the advanced workings have encountered unchartered wells, and in several cases explosions have resulted therefrom, but fortunately the explosions were not extensive.

There should be very carefully drawn provisions in the laws of the states where both coal and gas are found, requiring that wells, upon abandonment, be thoroughly plugged with concrete below the level of the coal seam, and preferably be left open above the coal seam, so that any gas which does leak through may escape to the surface.

In the interesting case already referred to, where gas appeared in mine workings, the gas did not come out through the pillar surrounding the well but appeared to one side and along a line extending for over a quarter of a mile. This line crossed a barrier pillar and the leaks or gas feeders which came through the floor extended some distance beyond the barrier pillar. The well had three lines of casings, one inside of the other, and the inner casing which came from the gas sands was supposed to be blocked off from leakage to the coal seam, along the outside of the casing, by a rubber gasket. The well did not have a large flow, but the pressure was high when it was capped. The cap extended over all three casings so that the pressure was alike in all, hence, any failure of, or lack of tightness in, the casings would cause a leak into the mine workings as already mentioned. The gas did not appear through the coal pillar, but evidently worked through a rock jointing below the coal or line of the structural weakness through which it worked and came up through the floor of the coal seam.

Explosions were caused in the two mines, but owing to the moist conditions in which the coal dust was kept the explosions were limited in extent.

Prof. Stoek: Mr. Rice raised the question of gas wells. In this state that matter has proved in the last six weeks, as possibly some of you know, to be a very present trouble. At one of the mines in the central part of this state, within the past six weeks, a well was being drilled; it happened to be through the shaft pillar, and a very decided flow of gas was encountered, sufficient to have blown up that mine if it had penetrated one of the workings. In the new mine law provision has been made, first, that all wells shall be located on mine maps, and second, that the driller of the well must locate it and file a record and plat with the county clerk, which becomes a part of the title record of the property. Then the commission found what a great many of the mining men certainly did not know: that there has been, for the last eight or ten years, a law on our books requiring all wells to be plugged from the bottom to the surface so that they are fairly protected under that.

A Bement, M. W. S. E.: Among the excellent suggestions, the one that has attracted my attention most is a provision for feeding the experimental mine with gas. I am inclined to think that much will come out of the possibility offered through this means. It is my opinion that gas plays a larger part in what is called dust explosions than is usually supposed. Formerly when there were explosions in mines it was thought that these were due to gas; then some one discovered that in many cases there was no indication of gas as far as could be ascertained, but that there was dust.

Then it occurred to somebody that in about 1878 there had been an explosion of flour in a flour mill in Minneapolis. This led to the idea that any inflammable, any combustible substance in the form of dust would explode, and that explosions in coal mines, where there was dust present, were very largely dust explosions. If we consider the flour dust which exploded at Minneapolis we see, as in the curves that Mr. Rice showed, that we have a substance that kindles very readily. We know that we can ignite wood by the use of a match, but we cannot ignite coal in that manner, even after reducing it to fine powder.

The anthracite mines of Pennsylvania are very dusty, but the coal is very hard and does not kindle easily; consequently there are no dust explosions. Bituminous coal, midway in character between anthracite and the vegetable flour dust, is more inflammable, but I am inclined to think that in almost all dust explosions there is a ***kindler*** present in the form of gas, although it may be a very minute quantity. Doubtless the provision which Mr. Rice has made to feed the experiment with gas will give some interesting results. It is possible that some such work could be carried out in the laboratory for the purpose of obtaining more exact and definite results.

A Member: Is the hydraulic mining cartridge meeting with favor among the mine operators?

Mr. Rice: It is making some progress. It requires special conditions,—that the coal should be very thoroughly undercut, that the roof should be strong enough so that the upward thrust will not crush into the roof, and that the coal must be of such structure that it will not shear off too readily causing the pressure to go to the back of the block to be broken down. On the other hand, the coal must have sufficient cleavage so that it will cut clean on either rib. I observed in a number of places where I saw the cartridge used that it broke down the particular class of coal very well, except that it did not take it out cleanly to the ribs. I think the machine is peculiarly advantageous in the longwall mines. If we had more longwall mines there would be a greater chance of using the cartridge because we would not have the corners to work into.

Prof. Stoek: Some of you may have seen the type of hydraulic cartridge that Mr. Scholz brought back from Germany. It works somewhat differently from the ordinary type, but with direct water pressure—water extending throughout the coal—rather than with the piston as with the ordinary hydraulic cartridge. It is promising by way of experiment, and much cheaper.

Mr. Rice: That is the Meissner pressure system; do you know whether Mr. Scholz has made any trial of it as yet?

Prof. Stoek: Mr. Scholz has sent the cartridge to some of the mines in the western part of the state and has sent one to Oklahoma, and is beginning to experiment with it. I have not talked with him concerning it, however, for some time.

John A. Garcia, M. W. S. E.: I am intensely interested in the subject of explosions in mines, but can add little in the way of discussion. I came here tonight to listen and to learn, not to say anything. I believe that the first thing we must do is to stop shooting coal off the solid, and that the next thing is to use permissible explosives. When we have done that we have taken a long step in the way of making the mine safe, and then we can go into refinements. But as long as the coal is shot off the solid in gaseous mines by the use of black powder, and holes are drilled in the ribs and filled with a half keg of powder, that process is going to blow up the mine. We have had a number of bad explosions in Illinois and Indiana, and in one instance in Indiana, which Mr. Rice remembers, some of the holes were five inches in diameter and had almost a keg of powder in them. It is reasonably certain that the mines will be blown up when that is done.

Again, we have to contend with the labor element. That element has secured such a grip on the business it is hard to enforce any discipline, and difficult to get anything done. In fact in the last three or four weeks they have insisted that we give them a permissible explosive for $2.45 when it costs $2.64 laid down on the ground. They said if we did not do so they would go back to black powder. We refused to do this and the mines have been shut down now for two weeks. I think it would be a good thing for the Government to take up the question of price of permissible explosives and see if we cannot reduce it to a point where we can give the explosives to the men at a reasonable price and insist upon their using them.

Prof. Stoek: One of the very interesting things to me in Mr. Rice's paper was the development of the science of coal mining. I think five years ago 99% of the people in this country would have laughed at the idea of going abroad and getting scientific instruments such as Mr. Rice has shown by lantern slides. Now people are certainly coming round to the idea that coal mining is a science and that it is not simply the result of practical experience. That to me is one of the encouraging parts of the whole thing.

F. W. De Wolf, M. W. S. E.: It is a great pleasure to have read the paper prepared by our fellow-member, Mr. Rice, and to have heard the further remarks made this evening. Some of us have been hearing for a year, or more, of the plan to acquire an experimental mine by the Bureau, but have had little conception of the purposes or methods of the proposed experiments.

Not being an engineer, in the usual sense, I can add nothing of value to the subject immediately in hand, but I should like to call attention to the beneficial campaign by the Bureau of Mines, in an effort to improve mining conditions. Among the various researches of peculiar importance to us in Illinois may be mentioned the experiments on explosibility of coal dust; tests of explosives, and announcements of "permissibles"; studies of exploded mines; primers for the ordinary miner in order to decrease dangerous practices; installation of rescue stations, cars, and apparatus.

We have benefited from the close co-operation maintained between the Federal Bureau and the State Geological Survey and Mining Department at the University. The first sub-station was located at Urbana, and its effective demonstrations led to the creation of the State Mine Rescue Commission. Dr. Holmes served on that and on the Illinois Coal Mining Investigating Commission, to our great benefit.

We look forward with great pleasure to further co-operation during the next two years—appropriations permitting. Among the measures which the Society recently endorsed was an appropriation to the State Geological Survey and to the Department of Mining at Urbana, for co-operative investigations with the U. S. Bureau of Mines. A tentative outline of the proposed investigations, though subject to much change by either addition or exclusion, is as follows:

SUGGESTED COOPERATIVE INVESTIGATIONS.

1. A study of gases in Illinois mines:
    (a) Method of occurrence.
    (b) Amount.
    (c) Kinds.
2. Mine Ventilation:
    (a) Construction cost and efficiency of various kinds of stoppings and overcasts.
    (b) Efficiency of different systems of ventilation.
    (c) Comparative tests of mine fans.
3. Methods of Mining:
    (a) Comparison of present methods (long wall, room and pillar), and panel in regard to amount of coal recovered.
    (b) Strength of coal in several seams and districts, and at various depths.

    - (c) Various sizes of pillars for different conditions of depth, and roof and floor materials.
    - (d) Amount, rate and effect of surface subsidence with partial and complete removal of coal.

4. Mining Wastes: a study of the various causes of present wastes.
5. Mine Supports:
    - (a) Comparison of various material used for mine supports.
    - (b) Methods of treating mine timber to prolong its life.
6. The Dust Problem:
    - (a) Explosibility of Illinois coal dust.
    - (b) Methods of preventing dust explosions.
7. Methods of bringing down coal.
    - (a) Comparison of blasting and hydraulic methods.
8. Mine accidents.
9. Studies of fire fighting and rescue methods as requested by Mine Rescue Commission.

To repeat what Professor Stoek has just said, we have truly entered on a new era in mining investigations. We all trust that the good work may go on rapidly.

ELECTRICITY IN ICE PLANTS

AUG. C. SMITH.

Presented April 26, 1911.

The question of electricity in ice plants is engaging the attention of central stations and power companies to no small extent, and likewise should be of similar interest to the manufacturers of refrigerating and electrical machinery..

Electric motors, operating ammonia compressors for refrigeration, have been in use for some time, but it is only of very recent years that they have been applied to compressors for ice making, especially on a large scale.

There have been many problems to overcome in applying electric power to ice making. One, the question of pure or distilled water, where the argument advanced was that if it is necessary to boil the water, why not produce live steam and operate steam-driven compressors, thereby getting power as a by-product at a cost of but little more? Another, flexibility of speed-control in the electric motor as compared with the steam-driven compressor for meeting varying atmospheric conditions, etc. This problem appeared even more serious when the type of motor using central-station power in most cases would be of the A. C. induction type.

Where pure water was obtainable, the plate system of ice-making helped to solve the first of these problems by taking the water as received and applying proper systems of filtration and agitation. To the writer's knowledge, this was the first electrically-equipped commercial ice plant on a large scale where purchased electric power was used and the A. C. induction type of motor applied to this class of work.

At first the two and three speed induction motor was applied to ammonia compressors, so that by the use of switching devices, changing the number of poles of the motor, the speed of the compressor could be varied, but only in two or three fixed steps. To still further extend this variation, different sizes of motor pulleys were at times kept on hand.

This arrangement does not provide the flexibility necessary or even desired, but it was economical from a power-consuming standpoint. On the contrary, however, it imposed a very low power factor in the motor when operating at reduced speed.

Finally the standard type of variable-speed induction-motor was applied, having external resistance-control and giving a flexibility of speed-range for the compressor equal to that of the steam-driven compressor. This was accompanied with poorer efficiency from a power-consuming standpoint when operating at reduced speeds, the power factor, however, remained practically constant at all speeds. Therefore, in ice plants where, during certain seasons of the year, there is a wide difference in output, and variable speed motors are used, better economy can be obtained by having two or more compressor units, proportioned with relation to one another, according to the local operating requirements of the plant. From an economic standpoint this is a very important detail in the engine-room design and should receive careful consideration.

THE PLATE SYSTEM.

In Fig. 1 we have a view of the engine room of an ice plant using the plate-system of ice-making. The compressor is of 100 ton (ice) capacity when operating at 62 r. p. m., is of the horizontal double-cylinder type, and is driven by rope from a 200 H. P. three-phase, 25 cycle, 2200 volt induction motor. The motor is small for the full capacity of the compressor, so the latter is operated at 54 r. p. m. at reduced capacity. The motor when originally installed was constant speed, but since then it has been changed to variable speed by the introduction of external-resistance control in the secondary of the motor, giving a range in speed from normal in 13 steps to 50% of normal. It is also possible to disconnect one side of the compressor, operating only the other side as a single engine, thereby increasing further the flexibility of the plant. There is now being installed in this plant another unit of 30 ton (ice) capacity. This machine will be operated by a 100 H. P. three-phase, 25 cycle, 2200 volt variable speed induction motor. This smaller unit will be used alone in winter months, and in summer in connection with the larger unit when necessary. The water in this plant is taken from the city supply, filtered, and turned into the tanks, producing excellent, pure, clear ice. During the process of freezing, the water is

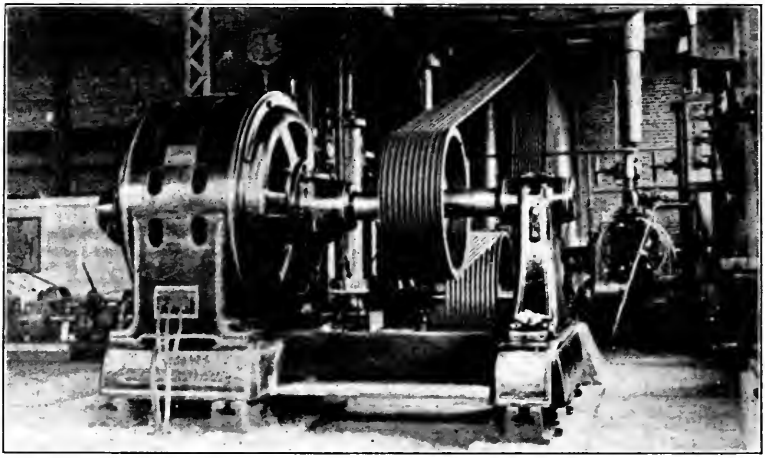


Fig. 1. Engine Room—Plant Plant.

constantly agitated by means of air which is supplied by a small blower operated by a 7½ H. P. motor.

In addition there is the following auxiliary apparatus operated by three-phase, 25 cycle, 440 volt induction motors:

Water pump for condenser belted to 7½ H. P. motor.
Water pump for tanks direct-connected to 6 H. P. motor.
Brine pump belted to 2 H. P. motor.
Ice saw by chain drive to 3 H. P. motor.
2 tilting tables, each belted to 2 H. P. motor.
1 ton ice elevator belted to 3 H. P. motor.
2 cranes, each equipped with a 3 H. P. and 5 H. P. motor.

The following table shows the production and energy-consumption of this plant monthly for the year 1910:

POWER CONSUMPTION MONTHLY FOR A PERIOD OF ONE YEAR IN AN ELECTRICALLY OPERATED 100-TON ICE PLANT USING THE PLATE SYSTEM.

The Crystal Ice and Storage Co., Buffalo, N. Y.

	—Tons of ice—					
1910.	Month.	Daily Average	Max. H. P.	H. P. Hours.	Max. H. P. per ton.	H. P. H. per ton.
Jan.	....	....	...	10,314	....	....
Feb.	1,420	50.7	145	98,214	2.86	69.2
Mar.	1,400	45.2	153	105,845	3.38	75.6
Apr.	1,168	38.9	139	78,933	3.58	67.6
May	1,786	57.6	138	101,798	2.40	57.0
June	1,037	34.6	278	120,720	8.00	116.4
July	2,294	74.0	280	201,791	3.78	88.0
Aug.	1,800	58.1	290	209,200	4.98	116.2
Sept.	2,244	74.8	283	198,157	3.78	88.3
Oct.	1,115	36.0	149	117,363	4.13	105.3
Nov.	1,019	34.0	141	98,320	4.14	96.5
Dec.	1,356	43.7	139	104,398	3.19	77.0
	16,639			1,445,053		86.8

The foregoing figures show some considerable variation in results from month to month during the year 1910, caused by local conditions pertaining to the operation of this plant during that period. One variation in particular was caused by operating at reduced capacity at intervals during certain months. This illustrates the necessity of a division of compressor unit, as previously mentioned, which this plant is now arranging for, and which will tend to reduce greatly the resultant cost of production.

It will be noted that the total annual production is 16,639 tons of ice, with an energy consumption of 1,445,053 H. P. hours, equivalent to 86.8 H. P. hours per ton of ice average for the year.

The total electric power cost for all energy supplied, including that for auxiliaries and lighting during this annual period, was $5,917.00. The cost per ton of ice was as follows:

Power	35.56 cents
All labor, including tank room and handling	36. cents
Total	71.56 cents

THE CAN SYSTEM.

The operations in the can system differ from those of the plate system. In the can system the water is first distilled or evaporated and in so doing it is customary to raise the water to high-pressure steam, using this steam for power purposes in the operation of the plant machinery and condensation therefrom for ice, after separating the engine oils, grease, dirt, etc.

As the condensed steam from the plant machinery is never sufficient to supply all the water needed for ice, a considerable amount of live steam is also used.

It would be considerably more expensive to operate a can-system plant by purchased electric power and evaporate the water by the usual boiler method, than by steam power where the necessary power is obtained as a by-product, and the exhaust steam is used for making ice. To overcome this excessive cost when using purchased power, supplementary distilling apparatus is used in connection with a comparatively small boiler equipment, so that for a given amount of fuel used a considerably greater amount of distillate is obtained than can be produced by usual boiler evaporation.

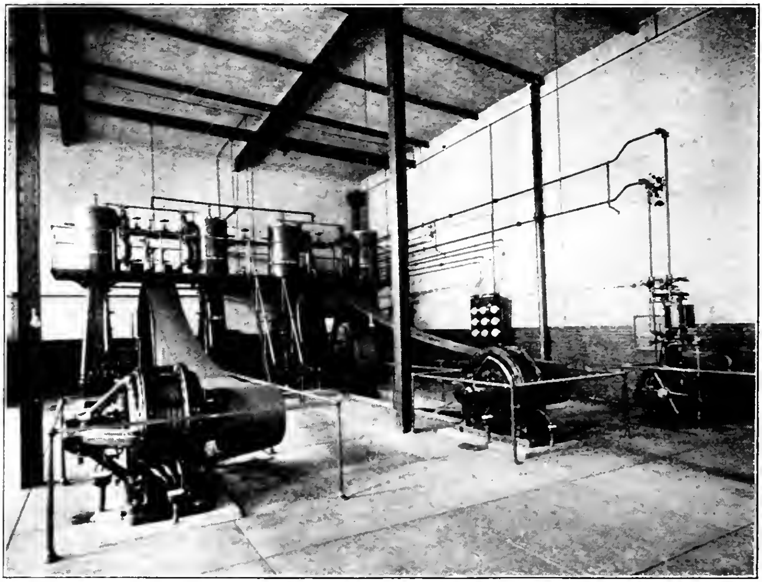


Fig. 2. Engine Room—Can Plant.

A 100 ton (ice) can-system plant equipped and operated in this manner is described herewith.

The boiler-room equipment consists of two 85 H. P. horizontal tubular boilers with mechanical stokers, either one of which is more than sufficient to evaporate the necessary water for the full 100 tons of ice in 24 hours.

Figure 2 illustrates the engine-room equipment of this plant, which consists of two vertical 45 ton (ice) two-cylinder, single-acting ammonia compressors operating at full normal speed of 72 r. p. m., each belt driven by a 175 H. P. 500 r. p. m. three-phase, 25 cycle, 2200 volt variable-speed induction motor.

By means of the speed control of these motors the compressors can be operated at thirteen different speeds continuously, from 72 r. p. m. maximum to 11 r. p. m. minimum.

The incoming wires for the supply of electric energy enter a suitable apartment through the walls and lead first to a primary incoming line panel, equipped with disconnecting switches and an automatic oil switch. From this panel the conductors are carried to individual motor-panels, and from thence to the motors. The resistance control is connected through a drum controller to the rotor of the induction motor.

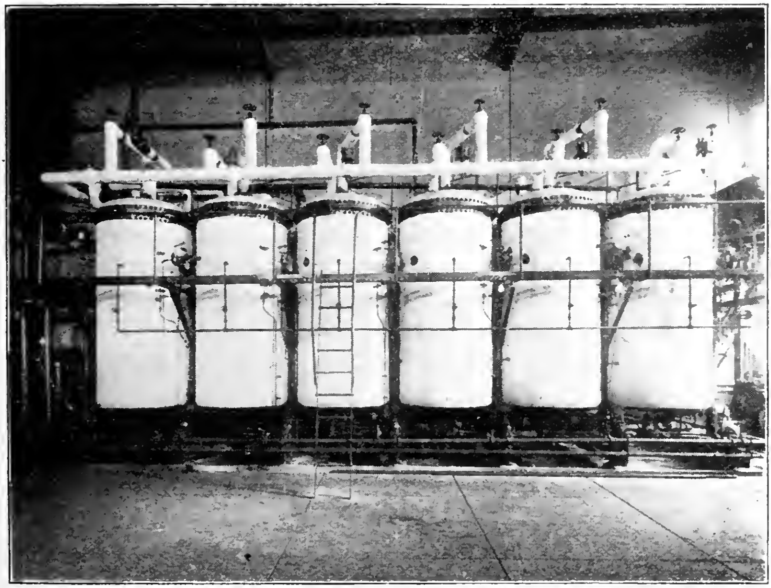


Fig. 3. Distilling Plant.

The efficiency of this type of motor is low at reduced speed, as the total energy input remains nearly constant for all speeds. It does, however, provide a flexibility of speed control practically equivalent to that of the steam-operated compressor, which is a very essential item in providing for varying atmospheric conditions. When it is necessary to reduce the output of this plant to one-half capacity or less, only one compressor unit is operated, a condition which exists during about four winter months of the year. The efficiency at this point of operation is as good as that obtained when operating the plant at full capacity. There is, however, a point which comes between one-half and full capacity of output when both compressors are operated at slightly reduced speed; this condition exists for two or three months in the year, at which time the efficiency is somewhat lower than that obtained at full capacity.

It is with these varying conditions of operation in view that the engine-room design in each and every plant must be given very careful consideration with regard to its particular operating conditions,

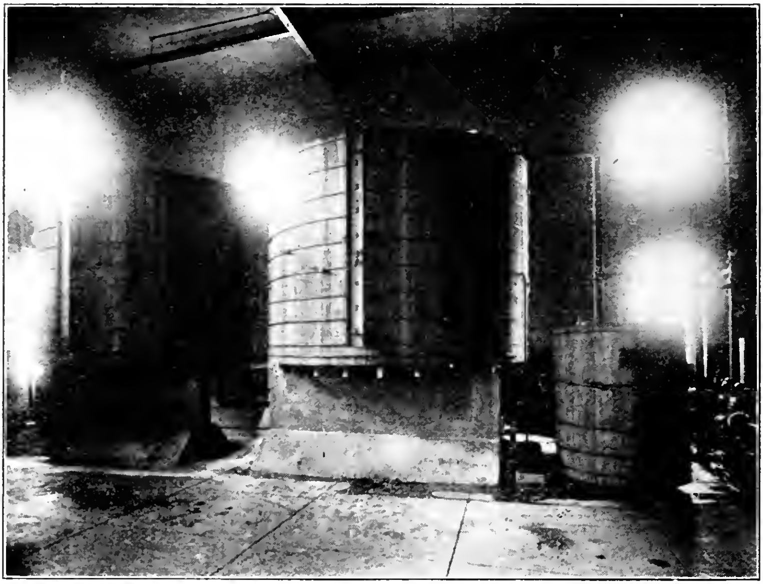


Fig. 4. Water Softening Apparatus.

so that the proportioning of compressor units with relation to one another will be such that for varying conditions of plant output throughout the year the compressors can be operated singly or together at or near full capacity, and thereby permit the motors to be operated at or near their normal full speed. The engine-room design can be carried to such a degree of refinement that the first cost will overbalance the resultant benefits derived from operating efficiencies. This must be guarded against by a little good judgment and some comparative figuring.

In addition to the foregoing electrical apparatus, the plant is equipped with two 20 kw. 2200 volt primary, 440 volt secondary, transformers for supplying power to auxiliaries, as follows:

4—3 H. P. constant-speed motors direct-connected to brine agitators.

1—25 H. P. variable-speed motor belted to condenser pump.

1—5 H. P. variable-speed motor belted to pumping-out machine.

1—5 H. P. variable-speed motor belted to soft-water pump.

1—1½ H. P. constant-speed motor belted to water-softener mixer.

2—3 H. P. variable-speed crane motors.

Making a total of 54½ H. P. in auxiliary motors.

Figure No. 3 shows a view of the distilling apparatus which is supplementary to the boiler equipment. This still consists of 12 cells, arranged in two banks, having a total capacity for handling 50,000 gallons of water in 24 hours, and for every pound of steam delivered to it at 100 lb. pressure the still is supposed to produce from 6 to 7 lb. of distillate, or it might be said, at this rate of distillation, for every pound of fuel from 40 to 50 lb. of distilled or evaporated water can be obtained.

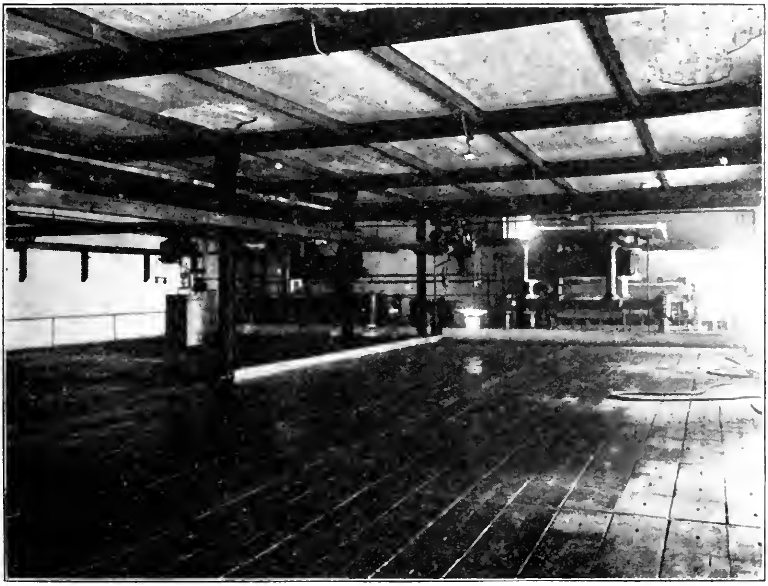


Fig. 5. Tank Room.

Figure No. 4 is a view of the water-softeners in use in this plant. The function of this apparatus is to soften the water received from the city supply to prevent scaling in the distilling equipment. After the water has been treated in the softener tanks and then filtered, it is pumped to the last or twelfth cell of the distilling equipment in which it is raised to a little above 212° Fahr. Therefore, any scale-forming matters which are not entirely eliminated in the process of treatment and filtration will be deposited in this last cell, and as all of the raw water fed to the other eleven cells is drawn from this last cell they are kept clean and free from scale.

This water-softening equipment has proven very satisfactory and has effected a marked increase in efficiency in the still over the results prior to its installation.

Figure No. 5 is a view of the tank room. Its arrangement is the same as that for a steam plant with the exception that cranes are electrically operated and the agitators driven by direct-connected vertical-shaft induction motors.

The ice produced by this plant is beautifully clear, so much so that a photograph has been taken of a man standing behind a couple of cakes of ice placed on edge, one above the other, to get a large enough screen to hide the man.

The following table gives for a period of one year, monthly production, average daily rate of production, maximum horse power demand, horse power hours, maximum horse power per ton, and horse power hours per ton of ice produced:

POWER CONSUMPTION MONTHLY FOR A PERIOD OF ONE YEAR IN AN ELECTRICALLY OPERATED, 100-TON ICE PLANT USING THE CAN SYSTEM.

	—Tons of ice—					
1910.	Month.	Daily. Average	Max. H. P.	H. P. Hours.	Max. H. P. per ton.	H. P. H. per ton.
Jan.	1,768	57.0	123	87,070	2.16	49.24
Feb.	1,549	55.3	137	79,450	2.48	51.29
Mar.	1,903	61.4	221	93,760	3.60	49.27
Apr.	2,732	91.1	232	164,558	2.55	60.23
May	2,651	85.5	257	165,488	3.01	62.42
June	3,024	100.8	300	188,666	2.98	62.39
July	3,442	111.0	314	219,265	2.83	63.70
Aug.	3,503	113.0	300	208,123	2.65	59.41
Sept.	3,514	117.1	291	209,027	2.49	59.48
Oct.	3,379	109.0	283	185,177	2.60	54.80
Nov.	982	32.7	137	88,070	4.19	89.68
Dec.	1,853	59.8	129	93,914	2.16	50.68
	30,300			1,772,568		58.50

From these figures it will be seen that the total annual production is 30,300 tons of ice, with an energy consumption of 1,772,568 H. P. hours, equivalent to 58.5 H. P. hours per ton of ice, average for the year, with a maximum of 63.7 in July, and a minimum of 49.24 in January (excluding November).

The total electric power cost for all energy supplied, including that for auxiliaries and lighting during this annual period, was $7,079.00. The coal consumption for evaporation and distillation of all water is 85.47 lb. per ton of ice at $2.50 per ton of 2000 lb.

The cost per ton of ice was as follows:

Power	23.36 cents
Fuel	10.68 cents
Engine and boiler room labor	15.51 cents
Total	49.55 cents
Or per 100 tons in 24 hours	$49.55
The cost of tank room labor was	12.55
Making a total cost per 100 tons of ice delivered to the platform	$62.10

For purposes of general comparison the following figures illustrate the cost of producing 100 tons of ice in 24 hours by a steam-operated plant based upon a boiler evaporation of 8 to 1, coal cost of $2.50 per ton delivered, and a daily evaporation of 250,000 lb. of water, with all power derived therefrom as a by-product.

Fuel		$39.06
Engine and boiler room labor—		
1 Chief Engineer	$5.00	
1 Asst. Engineer	3.00	
2 Oilers	5.00	
2 Firemen	6.00—	19.00
		$58.06

The foregoing results demonstrate that electric power can be successfully applied to commercial ice plants, especially on a large scale. The question of relative cost of production between a plant operated by purchased electric-power and generated steam-power rests entirely with the rate at which electric power is obtainable.

The plants described herein obtain a rate for electric power of $36.00 per horse power per year when the monthly maximum demand is 100 H. P.; $32.50 when 200 H. P., and $30.00 when 300 H. P. The monthly minimum is placed low, so that during the winter months when the energy consumption is light the plant will not be penalized by a heavy fixed charge.

Electric power applied to ice plants offers the same advantages over steam power as in other industrial plants. These advantages have long been recognized, so that the use of electric power in other industries has become almost universal. There is, furthermore, no question as to the quality and purity of product obtained from the electrically-operated ice plant, while with the steam-operated plant, wherein the exhaust is used for ice, there always exists that uncertainty of contamination from engine oils, grease, dirt, etc. It is an admitted fact that after steam has once been associated with oil (the oil at this state being almost a gas) it is difficult to clear the water of all traces of its presence, or should a break occur in the apparatus performing this work, the whole mass of water is liable to show traces of oil for some time to come.

The operating cost of the electric plant should therefore be rightfully compared with that of a steam plant which will give the same guarantee of purity of product.

Again, with the application of electric power to ice making and the elimination of coal, we eliminate all the troubles and annoyances coincident to the use of coal, such as storage space, handling facilities, smoke nuisance, etc., all of which are influencing factors in plant location. This question of possible plant location will be one of the important factors in the future in the establishment of a system in our large cities, consisting of a number of comparatively small plants located each with respect to the territory served, as opposed to large capacity plants with distributing stations.

Discussion.

Mr. Smith: The question of utilizing raw water for ice purposes is being looked into by a number of concerns. There are two or three methods on the market today, but none of them have been in operation long enough so that reliable data can be obtained. I think it will be found that obstacles will be met which will have to be overcome.

As to operating cost, that to my mind depends entirely upon a year's trial after the plant has been thoroughly worked down and refined, similar to the can plant which has been described tonight, which in my opinion is the ideal plant so far, in the United States. Considering the power consumed, I do not think there is any other plant that cán turn out more ice, better ice, or cheaper ice than this one.

Another question on which there seems to be quite a difference of opinion is that of variable-speed motors. There are good arguments on both sides, but all of the plants that I have had anything to do with, or have ever visited, where they did not have a speed control, the operating engineer wanted it, and said he could not get out good results without it; in all the plants where it has been installed it has been found indispensable. I am strongly of the opinion that a mistake is made if a plant is completed without either providing the resistance control in the first place, or arranging so that it can be added later on. This was demonstrated in the first plant mentioned tonight—the plate system. An effort was made to get along with two or three extra sheaves, or pulleys, but without success. Variations in steps can be obtained, but it will be found that the atmospheric conditions, particularly as to temperature, will invariably come in between the steps. The system of control does not handicap a plant in any way if it is not used.

G. T. Seely, M. W. S. E. (Chairman): We are fortunate in having such an interesting paper at this time in Chicago. There are a number of artificial ice plants in Chicago, but I believe there are none in operation at the present time where electricity is used for motive power, although one is about ready for operation. There are several phases in the Chicago situation, I imagine, which are different from the situation at Buffalo. Your power costs about ½c per kilowatt hour, does it not?

Mr. Smith: The resultant cost in the can-system plant is 4 mills per horse power hour. Of course that is due largely to the extremely high load-factor; that is, full 24 hours' use is obtained out of the power, and the power is paid for on a monthly basis. The minimum demand is fixed at 100 kilowatts. The usual demand, of course, is in excess of that. Only the actual demands are paid for, so that in operating steadily for 24 hours, full value is obtained out of the power that is paid for. That accounts for the very low resultant kilowatt-hour cost.

Mr. Seely: In Chicago, the ice for which the highest price is received is, I believe, for domestic use, distilled-water ice. Raw-water ice is brought from Wisconsin and some of the near-by lakes at very low cost, and with the cost of electric power here it would be almost necessary for the plants to make raw-water ice. In that way a market has to be found for that for domestic use around the flat buildings.

E. W. Lloyd (Commonwealth Edison Co.): I have nothing I can add to what the author has said relative to the power application to ice machines. The interesting point he brings out is one we have tried to convince the ice people of for nearly a year, and that is the fact that it takes less than 50 kilowatt hours of energy to make a ton of ice. I believe it has been demonstrated tonight that even 50 kilowatt hours is high, which is a source of gratification to me, and verifies statements I have made continually. I think that the central station companies of the country are under a great obligation to the author for the work he has done in connection with the application of electric power to the ice business. Those of us who are in the central station business are looking for a summer load, and the ice business provides an ideal one. The load factor is better in ice plants than in any industry, with the possible exception of textile mills and silk mills, when they are running under full conditions.

Another interesting point brought out by the author was the maximum horse power required per ton of actual ice, which the tables show under normal conditions to be about three. We had figured that 2.3 kilowatt hours per actual ton of ice was a fair statement to make to a consumer as to what he might expect in the way of maximum demand, and these figures again prove that statement.

We have, through the very interesting developments in Buffalo, been able to secure two pieces of business in the community connected with the manufacture of raw-water ice. As the author has said, there is no proof of the fact that raw-water ice can be produced that will be as good as other ice, but we have great hope that this may be accomplished. One of the companies purchasing this power is now turning over its compressors preparatory to starting. The other plant has been delayed, I understand, on account of labor troubles, for the time being, but it is expected that it will be in operation before summer time. The plants are slightly different; they both expect to produce raw-water ice, but the method of production of clear-water ice is more or less of a secret; that is, they claim to have some particular process of producing clear raw water ice with which I am not familiar. I am not an ice man in any sense of the word, so am not able to describe or tell you anything about that method; but the people with the money in the project seem to believe that they have solved the problem, having first satisfied themselves after making tests.

As to the statement regarding the value of distilled-water ice, I think there has been more or less misapprehension on the part of the general public as to the value of distilled-water ice. It is my opinion that there are many pounds of ice made throughout the United States, supposed to be distilled-water ice, that was never made from distilled water. After looking into this matter for many months, together with other members of our company, I have come to the conclusion that raw-water ice is a thing that is to come, that it is practically here, and that in a few years there will be a great many plants making raw-water ice to the satisfaction of the public in general. As a rule, Chicago water is considered good water, and I have been told by those who have made tests that they have been able to secure very clear ice.

Mr. Seely: Is it not true, Mr. Lloyd, that the cost of electric power here would be several times the cost per kilowatt hour in Buffalo, due to the fact that it is generated here by steam instead of water power?

Mr. Lloyd: No, that is not true.

Mr. Seely: Can you tell me what the difference would be between the costs?

Mr. Lloyd: In the first place, I am of the opinion that the Buffalo company is selling power too cheap. Without wishing to detract any from the work done by the Buffalo company or Mr. Smith—it is good work, first class, and a very great thing for us—I believe that the ice manufacturer can make ice at a profit to him, and a very handsome one at that, at a price per kilowatt hour considerably in excess of what Mr. Smith is paying. We have gone into the question of cost of ice, including fixed charges, in steam plants, ice loaded on the platform, and are very sure that the proposition we have offered these people is a good one; in fact, it is so good that they are satisfied: that is all you can ask or all they can ask.

We have a new schedule of rates that applies to business of this class, called the "Off-peak Schedule." It is a charge per kilowatt of demand, namely, $15.00 per kilowatt for the first 200 kilowatts, and $9.00 for each kilowatt of demand in excess of 200 per year, plus a kilowatt hour charge of about 95/100c on 60% load factor. This rate provides that the consumer shall stay off the peak of our load during the months of November, December, January, and February between the hours of four and eight P. M. That is not at all a hardship for the ice man and it is very nice business for us.

In regard to the annual load factor, we do not feel that we can sell electricity on any basis except the annual basis. Mr. Smith is selling on a monthly basis. Of course, we will admit that some concession is due a business like the ice business on account of its being so much of an off-peak proposition; that is to say, the volume of the energy is used in the summer months when we have the most power to sell; but the annual load factor, as he has brought out, is about 65%. That coincides with statements made by a man who is considered to be about the smartest ice man in this end of the country. He thought that was as good a load factor as could be obtained. There might be isolated cases where better load factors could be obtained—for instance, in a location where the ice could be delivered to consumers the year round. In residential territory I understand the consumption of ice in the winter time is only about 10% of that in the summer time.

Wm. B. Jackson, M. W. S. E.: I have one or two questions or suggestions, but first I would like to voice the expression that we are greatly indebted to Mr. Smith for giving us some real cold facts regarding the use of electric power in the manufacture of ice.

We are especially interested in the matter of the annual load-factor: If I remember rightly, the annual load-factor obtained by taking the average of the monthly load-factors was in the neighborhood of 90%, showing a remarkably uniform use of power during the individual months. When figured on the basis of the actual yearly load-factor (that is, the ratio of the average load for the year to the maximum load), it becomes approximately 65%. As we observe the table it is readily seen that the difference between 89% load factor and 65% load factor is occasioned entirely by increased load during the summer months. A load having a poor annual load-factor caused in this way, will prove a positive advantage to almost any electric lighting and power plant with the usual heavy winter load and light summer load, and should be more advantageous than a load having a 100% load factor, since it will serve to fill the summer hollows while relieving the plant during its heavy winter season.

Mr. Smith: The method on which the load-factor is based here is by months on the basis of the actual maximum monthly demands, as compared with the actual kilowatt hour consumption over that period. In the winter time, by virtue of the plant operating conditions, the maximum demand falls off; although the load-factor for those months is just the same as the monthly load-factor for other months, it remains high, and it seems to me that the monthly load-factor represents a value which is truer than the annual load-factor. As I understand from the power rates in Chicago, resultant rates are earned on the basis of the maximum yearly load-factor. In Buffalo we buy our power monthly, winter and summer, so that the value to us is on a monthly basis.

In connection with the raw-ice process, there are two methods before the public which are not secret. One is the cell system. That consists of a large tank filled with water and having pipes in sections or squares; in the sections a can having no bottom or top, is placed. The can is stationary. Underneath that can is a small pipe which conveys air supplied by a fan; air is circulated up through the water so that it carries the impurities to the top. On the top of the can a piece of iron is placed right across, which is frozen in the cake and used for handling purposes. Warm brine is turned into the pipes, and the ice is loosened from the can. Then the cakes of ice are taken and the butts or tops, including the iron, are cut off and thrown back into the tank for the purpose of cooling the water. That is the system which is being used in Buffalo, and I think it is going to work out very well.

The other system is what is called the center-freeze system. That is nothing more nor less than a straight can system with raw water, and just prior to the core freezing up the water is siphoned out of that core, which takes all of the impurities with it, and distilled water is put in; then the cake is frozen still more, so that the core will be frozen like the rest of the cake. That seems to be a very simple system.

I am hoping that the manufacturers of refrigerating machinery, and those who are trying to bring out new systems for the utilization of raw water, will feel that they can depend upon the local central stations, with their experts, and all the information they are able to get, and co-operate with them in working out this problem, because it is of just as much interest to the central station, if not more so, as to the man who is manufacturing refrigerating machinery. It is an important field and I think no one fully realizes today how big a field it will eventually become.

J. H. Warder (Secretary): Mr. Smith referred to the condition of the atmosphere. It would be of interest if he would explain that.

Mr. Smith: If one is running an ice plant today under certain head pressure and back pressure to meet certain temperatures, tomorrow the temperatures may change considerably. We frequently have that condition in Buffalo. In order to regulate the plant properly we have to regulate the pressures and we have to regulate the speed of the machinery.

Homer E. Niesz (Cosmopolitan Electric Co.): The ice-making machinery load is peculiar and to the central station manager it is most desirable, from the fact that the maximum load comes during the summer months, when the normal load on the central station is lowest. At that time there is more capacity to take care of that class of load, and the load is correspondingly lighter in the winter time, when the maximum on the station is higher. We are therefore anxious to get this class of business. Heretofore we have lacked the necessary information which has been supplied us this evening for the first time in such complete form and definite shape. The difficulty seems to be not so much the question of power as it is the question of the product which is manufactured, and that is the market condition as it relates to distilled-water ice. At the present time it is the opinion of ice manufacturers that the public wants distilled-water ice, and they are therefore planning their plants so that they can furnish that kind of ice. If distilled water is to be provided for the manufacturer of ice, unless a method can be brought out which will give them the distilled water and allow them to purchase their electric power, they will put in the steam engine. That has occurred recently in this city, where the proposition as to the relative feasibility of steam-driven or electrically-driven compressors was discussed a long time by the engineers and the central station companies. They decided to install steam-driven compressors because, in their opinion, they had to make distilled-water ice, and they could make their own power and provide distilled water by engine-driven units at a lower cost than they could provide distilled water and buy their electric power.

If we can educate the public to the idea of buying raw-water ice and paying the same price for it that they do for the distilled-water ice, there should be no difficulty in furnishing ice manufacturers with electric power at the rates that are now being quoted in this city, which are extremely low, although not as low as in Buffalo, for the reason given by Mr. Lloyd. At the prices for electric power in Chicago today, if the ice manufacturers can produce raw-water ice and find a market for it, I am convinced that they will buy electric power. If there is a means of producing distilled water at a sufficiently economical figure so that electric power can be utilized at the present rates, that will be done.

In my opinion it is a commercial condition in the sale of the product that determines whether the manufacturers will buy electricity for power, or whether they will use the steam which they manufacture in their own steam-generating plant, using the power as a by-product and leaving the main use of the boilers for furnishing their distilled water. That is the situation that confronts us, and the remedy for that is either to get cheap methods of distilling water direct for the manufacturing of ice, or to educate the public to the idea of using raw-water ice.

Fay Woodmansee: The talk this evening has been largely on the question of producing ice which is used really for refrigerating purposes. I should think they would use their energies in developing a small electric power refrigerating plant, which could be purchased for a comparatively small amount of money—for example, $150.00 or $200.00—and which the consumer could install in his evening—simply connecting his motor to his service. That would interested me market for the power, and the amount of ice used for cooling water for drinking purposes would be reduced considerably.

There is one feature in the manufacture of ice which has not been touched upon. That is, we often find plants around the country where the water for use in boilers has to be softened. After the water has gone through the boilers and been condensed in a condenser, it might be turned over to some ice-making company, who could add a certain amount of raw water, and make a very clear ice. This is a feature which could be utilized in such plants where softening apparatus is necessary, and where water has been evaporated and condensed in a condenser of a turbine. In turbine plants the water could be turned over to an ice company and I think it would make a good proposition from a power standpoint.

Mr. Smith: In going after the ice business in that way, I think it would be similar to the manufacturers of electrical machinery going after the isolated plant business. The large manufacturer or large distributer of ice is going to exist, there is no question about that, and if the central station sought the small ice-plant business and worked it up he would simply have the opposition of the large plants and never get their business. In the long run the latter would be far more valuable than the small isolated plants other than what we do go after and do get today,—as small packing houses, ice cream factories, and places of that kind, which the ice men recognize as justifiable on our part because such establishments have to have a certain amount of power, and they might carry it a little farther and make their own ice. But to seek the relatively small business of residences, hotels, office buildings, and places of that kind, would simply be opposing the ice men and losing their business, which I think is more valuable than the sum total of the small plants which we might get.

A Member: Will you please explain a little more about the distilling and condensation and the way the heat units are saved so that the maximum amount of water is evaported, in the still?

Mr. Smith: The distilling equipment consists of what is called a cell, which is nothing more nor less than an iron shell in which is a condenser consisting of a number of pipes. The steam enters the first condenser which is inside of the first still at about 100 lb. steam pressure. The condenser is inside of the shell. The space between the condenser and the outer shell is filled with raw water. As it comes from the twelfth cell it enters there at about 212°. The steam in the first condenser raises the water in the first cell to about 95 lb. pressure. That lowers the steam pressure in the first condenser, and the condensation from that condenser, in throwing off its heat into the raw water, drops down and is carried off as distillate. This process is carried on in the next cell, where it is pulled down another notch, until it comes to the last cell, where it is about 5 or 6 lb. The pressures are all equalized between the winter and equally divided so that the process is really we are therefore with water taken first at about 212°, the heat necessary to raise it being taken out of the live steam which comes in to the first still.

Mr. Seely: What is the increase in cost of distilled-water ice over raw-water ice in an electrical plant, including fuel, labor, and insurance and depreciation on the distilling apparatus?

Mr. Smith: The item of cost on the distilling is less than 11c per ton.

Mr. Seely: That is for fuel, I suppose?

Mr. Smith: Yes, for fuel. You can add to that the expense of two firemen.

Mr. Seely: I thought possibly you might have the figure in your mind.

Mr. Smith: Well, the firemen in this plant are paid $4.56 a day, which is equivalent to about 4½c. The cost per ton is about 15c, including boiler room labor and fuel. In addition to that, of course, there is the care and attention given to the distilling equipment and the water softeners, but these are taken care of by the engineroom workmen, so there is really no additional cost except in distilling. I would not be surprised if the cost would run up very close to 20c.

Mr. Warder: Does distilled-water ice cost about 20c a ton more than the raw-water ice?

Mr. Smith: We are making a comparison on using raw water and distilled water, but I am afraid we are getting into a comparison now which is hardly fair, because we have no figures on a raw-water plant and we are trying to make deductions by costs which enter into a plant using distilled water and allowing those in favor of raw water. I made the statement that I thought the cost would run up to 15c or 20c a ton, but it is only a guess. It is difficult to arrive at an exact figure.

Mr. Seely: About what would the overhead charges be for a ton of ice, 100 tons a day? I believe the cost of a plant is about $1,000 for daily ton capacity, is it not?

Mr. Smith: I think the fixed cost is something like 50c a ton, but that is an item that I have never looked into, closely. When the proposition first came up, I did ask as to the relative cost between a steam-operated plant and an electrically-operated plant, and was told that the prices were so close together they had no influence at all on the system adopted. So the fixed charges in construction with an electrically-operated plant would be about the same as those of a steam plant—just about 50c a ton.

In reply to Mr. Seely's second question, $1,000 for daily ton capacity is about right; that is, a plant of 100 tons a day capacity, without storage. The plant I have described cost more than $100,000, with the distilling apparatus.

W. L. Abbott, M. W. S. E.: I regret that I arrived too late this evening to hear the paper. The subject, however, is one which has interested me for some time. Some years ago I considered the feasibility of establishing an ice plant in connection with a steam-turbine plant where the water for the ice might be taken from the condenser of the turbine and free from oil. There are practical difficulties in the way of this scheme which render it impracticable. In the first place, there is seldom land enough available in connection with the power house for the establishment of an ice plant, with all the facilities in the way of trackage, loading platforms, and warehouses, which are usually required. In the second place, it would take from the turbine plant one of the particular and peculiar advantages which it enjoys, namely, that of having pure, distilled water for its boilers. There is, according to the estimates which I have made, a decided difference between the cost of an ice plant which manufactures ice from raw water and one which manufactures ice from distilled water; so much so that I consider that an electrically-operated plant which uses distilled water cannot run at a profit, in competition with a steam-driven plant, if it pays for its electrical energy a price which the local representatives say is right. An ice plant to be successful must have a supply of raw water so pure, or which can be made so pure by filtration, that the quality of its ice cannot be distinguished from that made by a plant which distills its water. There should be no reason why such ice is not as wholesome as that which is made from distilled water, and if it is free from objectionable germs,—something which we cannot say of natural ice,—it should certainly be quite as wholesome as though it were made from distilled water; in fact, in some ways it should be more desirable on account of having the natural flavor and composition of water which people are accustomed to drink.

One point which developed in our consideration, and which I have not heard mentioned here tonight, is the economical size of an ice plant. It should be of such a size and of such limitations that its product could find a market within easy teaming distance,—say within a radius of two miles,—and for a large city that size is limited, I believe, to 100 to 150 tons. I think it is more feasible to build an electrically-driven ice plant of 150 tons capacity than a steam-driven plant with that limitation.

Paul P. Bird, M. W. S. E.: Mr. Jackson very innocently remarked a little while ago that Mr. Smith had given us some "cold facts." The cold fact that chiefly appeals to me is that it has been conclusively proven that an ice plant can be operated successfully from central-station service. In Buffalo several ice plants are being so operated, and in Chicago two plants are ready to start up this season. These plants are not only being operated successfully from a practical standpoint but also from a commercial standpoint. This means that the electrically-operated ice-manufacturing plant is now well established, and from now on it is merely a question of development, which adds a new field to the central-station business. At first, the central station made electricity merely for use in lighting; then it took on power business in various forms, and year by year it has been getting into new phases of the power business. The ice plant presents a very attractive opportunity to the central station on account of its load factor.

P. B. Woodworth, M. W. S. E.: From engineering data presented in the paper it appears that it will be to the advantage of the producers of electrical energy and the ice plant to have electrically-operated ice plants. There is one thing that stands in the way, and that is the important point mentioned by Mr. Niesz,—that the public must be educated to understand that ice made from raw Chicago water is just as good as the distilled-water ice. As a result of a number of analyses made at the Lewis Institute, I am confident that Mr. Lloyd is correct in stating that a good deal of the ice now on the market and sold as distilled-water ice is really raw-water ice. Electrical men should assist in the education campaign for the use of raw-water ice. Lewis Institute will be glad to make analyses of ice to determine the number of bacteria or other harmful contents.

Mr. Steinberg: On the subject of the education of people as to distilled-water ice, I do not think they are educated to distilled-water ice but to clear ice. If raw-water ice could be made so that it would be absolutely pure and clear, there would be no objection to it. If the distilled-water ice were not clear, there would probably be more objection to that class of ice than the other, because some people have a vague idea of the manner in which it is made, thinking that the ammonia or other compounds or chemicals enter the cans, and that the ice has in it something besides the distilled water in order to finish this process of freezing.

This center-freeze idea seems very plausible, if that water can be siphoned out, because the objectionable features in all cakes of ice occur at the center. I would ask Mr. Smith what he thinks causes that redness in the center of the cakes made with the cell system. That is a very objectionable feature in distilled-water ice.

Another point in regard to these isolated plants: I think they would not be successful because a refrigerator system is extremely complex; the ammonia must be regulated closely to vary with the amount of freezing that has to be done or the system will get out of order. Also, the jackets on the compressor must be watched very closely, as to overheating, or a very high pressure will result. This blows the gaskets on the joints of the back pressure system, causing an annoying leakage of the ammonia.

Mr. Jones: I would like to add that one of our newest and highest-priced hotels here makes all its ice out of lake water, and if it is all right there it should be all right for everybody.

J. H. Delany: I understood the author to say that with the can system, after the cake had become frozen with the exception of the core, the latter was siphoned out and the space filled with distilled water; also, that in siphoning out this still liquid core, the impurities were removed. On account of lack of experience with ice plants, it is not clear to me why the impurities should center at the core. Possibly Mr. Smith can enlighten me.

Mr. Smith: I do not know whether I can explain that or not, but it is a fact that as water freezes the impurities are segregated and remain in the water. That is the secret of the plate system of freezing up against a hard plate, forming to a certain extent, but not taking up the entire cell, so that the impurities always rest in the water which is still surrounding the ice, the action of freezing driving all impurities away from the ice. In the cell system, the impurities are carried to the surface and cut off. In the center-freeze system the impurities as well as the air are carried to the center and drawn off or siphoned off.

Mr. Seely: In the can system it is true, I believe, that the water freezes from the outside of the can towards the center and leaves a very small portion in the center which contains all the impurities and the air, consequently it is an easy matter to remove them.

Mr. Smith: The point has been brought out that it is not so much impure water that we are worrying about in the raw-water ice as it is the discoloration of the ice. That is the whole trouble. It is not a question of how good the ice is, but how good it looks. If the public did not care so much about the looks, anybody could make raw-water ice. It is easier than bothering with the still. But the trouble arises in trying to turn out raw-water ice which is just as clear as distilled-water ice. In most hotels where they make their own ice they make it from raw water, and you will notice that ordinarily or frequently the ice you get in those hotels is white or chalky. It is not so much a question of distillation as it is to get an ice that looks good. That is what the people seem to want to buy.

H. S. Pardee: In the issue of *The Electrical World,* of April 20, 1911, there is a very complete description of a can system which has been installed in this city, and I presume it is the same one to which Mr. Jones refers,—that at the Blackstone Hotel,—in which they claim to make perfectly pure ice from raw water, drawing off the impure water from the bottom of the core. The principle of segregation in that core I understand is the same as the formation of piping in steel ingots. Or, if we had a solution of salt water, pure ice would first crystallize on the outside, gradually increasing the concentration of salt in the unfrozen part in the center, until finally the salt would be in the core. That is the principle on which the impurities and air gradually gather in the center where they can be drawn off. The science of metallurgy probably offers the best explanation of this phenomenon, which is described in the first part of a work by H. M. Howe, "Iron, Steel, and Other Alloys."

In the hotel installation referred to, each can is a separate unit, surrounded by a warming jacket for separating the ice from the can. A pipe is attached to the lower end of the can, from which the impure water in the center is drawn off. Inside this pipe is a smaller one through which air is bubbled.

I have understood that contained air is what makes the ice chalky. I should like to have Mr. Smith explain how air-agitation clears the ice.

Mr. Smith: It is the air that is contained in the water that gives the white appearance; the water in bubbling up through the center simply agitates the whole mass of water and in that way gradually carries the air which is in the water to the surface.

Mr. Jackson: Is not the ice just as good at the center?

Mr. Smith: Yes; there is usually one little jet of air in the center which bubbles up and seems to carry the rest of the air along by a mechanical operation or agitation of the water. We can sometimes separate air from water by passing it down over a rough surface which is merely a process of agitation.

A Member: In the hotel business, there is some objection to ice of a white appearance, as it is thought that a piece of white ice will not last as long as perfectly clear ice.

Mr. Smith: It may be that the ice was not frozen so hard.

The Member: Our trouble was in freezing it too hard.

Mr. Smith: The trouble in freezing ice too hard is that it becomes brittle.

F. F. Fowle: There are two points in this paper which particularly impressed me. The annual load factor is remarkably high and the annual maximum demand occurs in the summer. These features establish clearly the desirability of such a load from the central station standpoint, which has already been discussed. But the question of raw versus distilled water seems to be a most important factor in the economy of electric power for driving the compressors. In the case of cold-storage warehouses, however, there is no question of ice making, but merely one of refrigeration. Here it seems that there ought to be a new field for the central station, since so many cold-storage systems are operated by isolated plants. Where the conditions for the purchase of electric power make ice manufacture by this method economical, as described in Mr. Smith's paper, it seems proper to expect that cold storage and refrigeration can use electric power more economically than steam.

But this paper makes it clear that the manufacture of ice ought to be very attractive to small central stations. Of course, where the population served is small, the cost of production in a plant of limited size may not be low enough to compete with natural ice. Still there should be many instances where artificial ice can be produced at sufficiently low cost to enter into competition successfull
small central station needs a summer load, prefera
Ice making meets this need in a most ide
This brings out the
utilities in a sm

ust was born Nov. 26, 1832, in
father died in 1834, leaving a daughter
old, and Henry not yet two years old. His early education was obtained in the public schools of Springfield, and the Connecticut Literary Institution, Suffield, Conn. After graduation from the latter he assumed a clerkship in a mercantile house in Springfield.

On reaching his majority, he was so thoroughly imbued with the superior advantages afforded the ambitious young man in the then young and rapidly growing Chicago, that twelve hours after his clerkship engagement expired he started westward, arriving in Chicago March 2, 1854. Here he very soon secured employment in the office of Stone & Boomer, bridge builders. He seized the opportunity this position offered to acquire a practical knowledge of this branch of engineering, to which almost his entire after life was devoted. During 1855-6, when this firm was constructing the Rock Island Bridge over the Mississippi river, he was stationed at Davenport, Iowa, and was on the first locomotive that crossed the river.

During his over three years' service in the Civil War, in which he enlisted August 12, 1861, his knowledge of bridge building was utilized in bridge construction and field fortifications. During the Atlanta campaign, from Chattanooga to Atlanta, he had charge of the construction of field works and fortifications extending over about thirty miles. His services in the army were highly creditable, and, were it appropriate here, it would be a great pleasure to record many important events in his military career.

It does not seem inappropriate, however, to mention briefly a most important and daring act which made possible the successful evacuation of Island No. 10 on the Mississippi river. In civilian dress, under cover of night, he embarked in a skiff with a native familiar with the locality, and by a tortuous course across the peninsula emerged upon the Mississippi. At two o'clock in the morning he reported to Gen. Pope personally, on the practicability of making a channel by this route. At a conference of generals the feasibility of his plan was recognized, and the following night Adjutant Rust returned with dispatches from Gen. Pope to Commodore Foote and Gen. Buford which dispatches gave information of a plan to make a channel across the peninsula through the timber. This enterprise was promptly undertaken, resulting in the successful evacuation of Island No. 10.

In the battle of Rocky Face Ridge, one of the many in which he was engaged, he was wounded in the head while in command of the advance line. When mustered out of the service he held the rank of Major of the 27th Regiment, Illinois Infantry.

Upon the termination of his army life he returned to Chicago, where he married Mary Sterling De Forrest, who died about fifteen years ago. Immediately after his marriage he went to Nashville, Tenn., where he engaged in the execution of large contracts with the U. S. Government for the rebuilding of railroad bridges, destroyed during the war, on various lines in Tennessee, Alabama, and Georgia.

In 1867 he again returned to Chicago and entered into partnership with L. C. Boynton, under the name of Boynton & Rust, Engineers and Bridge Builders. This firm constructed some of the earliest combination truss and draw bridges, as those at Peru and Henry, over the Illinois River.

In 1870 the business of Boynton & Rust was merged with that of L. B. Boomer & Co., and formed the American Bridge Co., of which Major Rust was Vice-President and General Manager, during the existence of that company, from 1870 to 1879. In this capacity he was influential in obtaining and executing many large contracts for the company—namely, the Missouri River bridges at Omaha, Neb., Atchison, Kans., Glasgow and Booneville, Mo.; and the bridges over the Mississippi River at Hastings, Winona and La Crosse; also the Point (suspension) Bridge over the Monongahela River at Pittsburgh, and the Poughkeepsie Bridge over the Hudson River, for which that company put in the foundations in 1877-8.

He continued in the bridge and contracting business as the firm of Rust & Coolidge from 1879 to 1885, constructing the pneumatic work of the Bismarck Bridge over the Missouri River on the Northern Pacific Ry., and many spans on the line through Montana; also important spans and trestles on the Canadian Pacific R. R., including the span over the gulch at Selkirk, B. C.

Their work included pneumatic substructure and the superstructure of bridges in Arkansas, and over the Arkansas and White Rivers; also the structural iron work of several Chicago buildings, and the present Rush Street Bridge. For some years after the dissolution of this partnership, Major Rust was occupied in railroad construction, notably the Chicago entrance for the Grand Trunk Ry. of Canada; also the securing of an entrance to, and providing terminal facilities for the Wisconsin Central Railroad in Chicago.

Major Rust became a member of the Western Society of Engineers in 1877, and had membership in the Grand Army of the Republic, the Society of the Army of the Cumberland, and the Military Order Loyal Legion; also the Union League, and Washington Park Clubs, Chicago, and was officially connected with representative philanthropic, educational, and other organizations aiming to serve the public weal. From its early organization he was a Trustee of the Chicago University, and contributed liberally, both in time and money, to its advancement and, until quite recently, remained in active connection with the University as comptroller.

After a most useful, active, and exemplary life Major Rust died Feb. 5, 1911. Of his four children the following survive him: Bessie Sterling, wife of James W. Johnston; Philip De Forrest; and Mary Converse, wife of Enos M. Barton.

(Signed) HIERO B. HERR,
G. A. M. LILJENCRANTZ,
Committee.

WILLIAM B. EWING, M. W. S. E.

Died April 8, 1911

William Bion Ewing was born in Williamsburg, Pa., June 21, 1858. His father, William Ewing, Sr., was born at Manor-Hill, Huntingdon Co., Pa. Just prior to the Civil War he moved with his family to the city of Huntington, Ind., where for 40 years he was a prominent merchant.

His mother was Anna Ruhl, a daughter of John Ruhl of Williamsburg, Pa., who was one of the engineers on the Brooklyn Bridge construction under John A. Roebling, and it was while visiting this construction with his grandfather that Mr. Ewing conceived the idea of becoming a civil engineer.

Mr. Ewing's early life was spent in Huntington, Ind., and in 1883 he graduated from the Civil Engineering Department of Cornell University, Ithaca, N. Y.

His college vacations were spent in the employ of the Toledo, Delphos, and Burlington R. R. Co. After his graduation he entered the employ of the Department of Public Works of New York City, and was assigned to duty on the survey of the Croton Aqueduct, where he remained until 1886, when he came to Chicago and entered the service of the Chicago & Northwestern Ry. Co. He spent two years in locating new lines in the northern peninsula of Michigan and in Minnesota.

Returning to Chicago in 1888 he was employed by the Union Stock Yards Co., in the construction of warehouses, viaducts, pavements, and switches. In 1889 he again served the Chicago & Northwestern Ry. Co. in improving their property within the city of Chicago.

In 1890 he assisted in the making of a survey which required the measurement of all the railroads in the State of Michigan. From 1891 to 1895 he was mainly employed in the service of the Chicago Heights Land Association, where he laid out that now flourishing town, covering some 400 acres. He designed their system of water works and sewers and laid out many of the important industries located there, planning street improvements with steam and electric railroads that serve the town and its factories.

From 1895 until his death he practiced his profession of civil, sanitary, and municipal engineer, with headquarters in Chicago, and during these years his practice brought to him the wide reputation which he enjoyed, as well as a host of personal friends.

Among the municipal works which he designed and many of which were constructed under his immediate supervision were the water works system of Cazenovia, New York, Duquoin, Chicago Heights, LaGrange Park, Melrose Park, and Summit, Illinois; and sewerage systems for LaGrange, LaGrange Park, Chicago Heights, Wheaton, Geneseo, Dixon, Barrington, Palatine, Arlington Heights, Dalton, Riverdale, Burnham, West Hammond, and Lyons, Illinois; and Greensburg, Indiana.

In addition to the above noted works, Mr. Ewing has had charge of installing the underground pneumatic tubes for the *Chicago American* and *Chicago Tribune,* and did similar service for the *Associated Press.* In 1900 he was selected to assist Mr. Desmond FitzGerald, C. E., in his investigation and report upon the Chicago Drainage Channel. In addition to his private work he has acted as engineer for a large number of the suburban towns in the vicinity of Chicago, and has designed and constructed a number of sewage-disposal works. At the time of his death he was on his way to inspect a plant which he was constructing for La Grange, Illinois,—the first permanent plant of the sprinkling-filter type for sewage purification to be constructed in the state of Illinois.

On April 5, 1893, Mr. Ewing was united in marriage to Miss Mary E. Crandal, a daughter of Edward M. Crandal, of Stevensville, Pa., who in the late fifties moved to Illinois, served in the Civil War and was the inventor of a barb wire fencing.

Mr. Ewing was a member of the Western Society of Engineers since 1891, and of the American Society of Civil Engineers since 1898. He was also a member of the Suburban Club of LaGrange, LaGrange Lodge No. 777, A., F. & A. M., and Palisades Park Association of Covert, Mich.

(Signed) W. S. Shields,
Langdon Pearse,
Edwin Hancock,
Committee.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS.

Regular Meeting, September 6, 1911.

The first meeting of the Society after the summer vacation period, being a regular meeting, was held Wednesday evening, September 6.

The meeting was called to order about 8:15 p. m. with Past-President W. H. Finley presiding, and about 75 members and guests present.

The minutes of the regular meeting of June 7 were not read but were accepted as printed in the JOURNAL. The Secretary reported from the Board of Direction that the following had been elected into membership since the last meeting of the Society:

The Board Meeting of June 30.

Perry Barker, Boston, transferred to	Associate Member
C. T. Barnum, Madison, Wis.	Member
George W. Brady, Chicago, transferred to	Associate Member
H. J. Burt, Chicago	Member
Joseph L. Canby, Danville, Ill.	Junior Member
Ernest A. Clark, Chicago	Member
H. W. Clausen, Chicago, transferred to	Associate Member
H. E. Goldberg, Chicago	Member
Edward Gudeman, Chicago	Member
Leo B. Hollingsworth, W. Lafayette, Ind.	Student Member
Charles I. Jones, La Junta, Colo.	Associate Member
Tom P. Kester, Chicago	Associate Member
E. F. Manson, Freeport, Ill.	Associate Member
E. Robins Morgan, Chicago, transferred to	Member
H. S. Shimizu, Chicago	Member
H. A. Tedman, Chicago, transferred to	Associate Member
S. A. Willmarth, Chicago, transferred to	Associate Member
Fred N. Wilson, Chicago, transferred to	Associate Member

The Board Meeting of August 1

Frank A. Berry, Chicago	Associate Member
Stanley G. Cutter, Chicago	Junior Member
Robert S. Draper, Chicago, transferred to	Associate Member
Allen L. Fox, Chicago Heights, Ill.	Member
Edwin O. Greifenhagen, Chicago	Associate Member
H. A. Johnson, La Grange, Ill., transferred to	Associate Member
George M. O'Rourke, Tutwiler, Miss.	Junior Member
John T. Walbridge, Chicago, transferred to	Associate Member
Frank G. Walter, Jr., Chicago, transferred to	Associate Member

The Board Meeting of September 5.

John A. Boschetti, Chicago	Associate Member
C. A. Henderson, Abbeville, S. C.	Associate Member
E. S. Jenison, Jr., Chicago	Junior Member
Arthur S. Lewis, Chicago, transferred to	Associate Member
Lloyd E. Ross, Chicago, transferred to	Affiliated Member

The following new applications were reported as having been received:

Grant A. Caproni, Salt Lake City, Utah, and Lockwood J. Towne, Chicago.

The Secretary reported the death of the following from our membership:

Wm. Krames, Kansas City, Mo	April 25, 1911
Adam Comstock, Joliet, Ill	August 16, 1911
W. D. Taylor, Chicago	August 26, 1911

The Secretary announced that as a result of a referendum vote from the resident membership, the Board of Direction had set the evening for meetings of the Society as Monday, to be effective after the end of the current year.

There being no further business Mr. W. C. Armstrong, M. W. S. E., was introduced, who presented his paper on "The New Passenger Terminal of the C. & N. W. Ry. Co."

Discussion followed from Messrs. W. E. Symons, C. R. Dart, A. Reichmann, T. L. D. Hadwen, L. K. Sherman, S. T. Smetters, and John Brunner.

The meeting adjourned at 10:15 p. m.

J. H. Warder, Secretary.

BOOK REVIEWS*

WHITTAKER'S ELECTRICAL ENGINEERS' POCKET BOOK. Edited by Kenelm Edgcumbe, M. I. E. E., A. M. Inst. C. E., published by Whittaker & Co., London, and by Macmillan Co., New York, 1911. 3rd ed.; cloth, 6½ by 4 in.; pp. 597. Price, $2.00.

This book is the third edition, revised to 1911. It is of true pocket book size, 4 by 6½ inches. The paper is opaque enough for easy reading and thick enough for convenient turning of pages. There are ample cross references within the work and a satisfactory amount of reference to authorities and to related bibliography. There are 181 figures and a large number of tables.

The use of bold faced type increases the value of the book for reference purposes; a number of the formulæ are composed of mathematically related groups of words instead of arbitrary symbols, and in such cases that treatment relieves the student from the slight distraction of remembering or looking up the meanings of the symbols.

The practice described is in large measure entirely general, but where the references are to legal matters and to costs they are in terms relating to Great Britain only.

An excellent index is appended to the book. S. G. M.

THE PRODUCTION OF MALLEABLE CASTINGS. By Richard Moldenke. The Penton Publishing Co., Cleveland, 1910. Cloth, 6 by 9 in.; pp. 125, and copious index, with about 35 good illustrations. Price, $3.00.

This is a practical treatise on the processes involved in the manufacture of malleable cast iron, written by one who has had many years' experience in foundry work generally, and especially in this particular branch. It is the first authoritative book on that subject, and has been elaborated from a series of articles originally contributed to *Foundry*. But much new matter has been added—working-data and illustrations—making the book a valuable storehouse of practical information for all who are interested in the production of malleable castings.

Chapter I introduces the history early development and present importance of the malleable iron industry.

Chapter II gives the characteristics of malleable cast iron.

Chapter III treats of the testing of malleable cast iron.

Chapter IV discourses on the pattern shop, while Chapter V gives the moulding methods in the foundry for this class of work.

Chapter VI takes up the subject of melting processes.

Following this, Chapters VII and VIII treat of the construction and operation of the air furnace, and of the open hearth furnace. As connected with the latter, the next, Chapter IX, tells of the use of gas producers in malleable foundries. Next comes the important chapter, X, on the mixing of the charges (of the raw iron) for malleable iron, while Chapter XI takes up the subject of casting of malleable iron. The next step is the annealing of malleable castings, which is the subject of Chapter XII.

An important point in the industry is the study of the fracture of malleable castings, by which to determine whether proper results are being obtained, which is the subject of Chapter XIII.

The temperatures of the melting of the iron and of the annealing process is of great importance, and this can best be determined by the pyrometer—the subject of Chapter XIV.

In conclusion, Chapter XV takes up the cost of malleable castings—

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*The books noted in these reviews are in the library of this Society.

an important subject—which is fully analyzed by the author, and in which he shows where some foundrymen err in arriving at the cost of the work, resulting in taking some work at too low a price.

Altogether, the book is a valuable addition to a technical library, and thanks are due the author for what he has written, and to the publishers for what they have done. The book is handsomely printed and illustrated.

NOTES ON PLATE-GIRDER DESIGN. By Clarence W. Hudson, C. E., Prof. of Civil Engineering, Polytechnic Inst. of Brooklyn, New York. John Wiley & Sons. 1911. Cloth; 6 by 9 in.; pp. 75. Price, $1.50 net.

As stated in the preface, this book is intended to be used in the class room and by students, and the text in general is written with this in view. For this work to be of value to the practicing engineer, the principles stated should be placed in heavy type so as to be easily referred to. The work could be greatly improved both for the student and the general engineer, by having adequate and precise illustrations, and also various diagrams.

Page 2. "The following drawings are meant to illustrate some of the most essential features of plate-girder construction. They are, therefore, not meant to be casually inspected, but thoroughly studied, and the function of the various parts in carrying a load to the supports, the makeup of the parts and their connection, each to each clearly understood." The designs taken are not well chosen to illustrate some of the points made in the text. Fig. 1a shows a single-track deck plate-girder bridge. The general criticisms on the designs shown, without comment, are that the flange section is not well proportioned, and the web plates are not spliced for bending moment. The end stiffeners are preferably placed with backs turned in, rather than with backs turned out, giving better bearings on lower flange angles. On the design drawings it is of value to have the angle billed, with the leg showing billed first; for example, two angles 5 by 3½ by 7-16 should be billed, two angles 3½ by 5 by 7-16, 3½-inch leg against the web, and the 5-inch leg outstanding. It is good design to have the lateral plates connected to the cross frames. It is not shown in the design.

Figure 1b shows a single-track through plate-girder bridge. The criticisms in general on deck designs are applicable to the through design. It is not considered that the angle knee brace of the floor beams to girders, shown on the drawing, is good engineering. The number of rivets, as shown in the end of floor beams, is not sufficient. In splicing the lateral angles it is better to use plates wider than the leg of the angles.

The value of the 7 by ⅜-inch splice plates, shown on page 47, is rather doubtful. It is the opinion of the reviewer that it would be better to place plates 10 or 12 inches in width against web, instead of the narrow plates on the legs of the angles.

"Stiffeners supporting concentrated loads may be designed as columns with the formula $P = 16{,}000 - 70\dfrac{l}{r}$, in which l should be taken as one-half the girder depth and r as the radius of gyration about an axis in the longitudinal center line of the girder." Instead of using one-half the depth of the girder, it is good design to use the full depth of the girder, as the stress may not be well distributed in the web.

Criterion for maximum bending moments applies to through girders at panel points only.

The book is well written and quite complete in the presentation of the theory and fundamental principles of plate girders. S. T. S.

CHRYSOTILE-ASBESTOS: ITS OCCURRENCE, EXPLOITATION, MILLING, AND USES. By Fritz Cirkel, M. E., Canada Department of Mines. Bulletin 69, Mines Branch, Ottawa, Canada. 1910. 6⅝ by 10 in; stiff paper cover, 316 pp., 88 figures, 66 plates and 2 maps.

This valuable and very interesting government report, issued by our near northern neighbor, differs from many government reports, in that it is so readable. Much of the interest depends upon the novelty of the very recent development of use of that remarkable material, asbestos. The development of this mining industry in Canada has been rapid, the increase of tonnage and of value in the last half dozen years being nearly 100 per cent. This great increase has been due to increased uses for the material, which led to enlargement of existing and the discovery of new workings. By the way, the author speaks of these as *quarries* and not as mines, as more in keeping with the facts of the case, the mode of occurrence, and manner of recovery.

Chapter I gives some history of the early knowledge of asbestos and then states its physical and chemical properties. The asbestos minerals are described as Antophyllite, Amphibole, and Serpentine. The latter consists of Picrolite, Talc, and Chrysotile. It is this last that is the material which is the subject of this report. The physical properties and chemical composition of this material, with a summary of asbestos minerals, forms the conclusion of this chapter.

Chapter II treats of the Canadian serpentine area and productive serpentine range, and also makes comparisons of the Canadian mineral of different localities and with the serpentines of other countries.

Chapter III describes the quarrying of asbestos, including stripping and quarry work proper, use of explosives, comparison of hand and machine drilling and costs, the separation and removal of rock, and ore quarry machinery, as derricks, hoisting machinery, efficiency, etc.

Chapter IV describes the dressing of asbestos for market with a summary of the principles of the separation of asbestos, and concludes with a description of the general features of the mills in the district. The drying problem is an important one, also the subject of crushing the rock by various forms of breakers, rolls, pulverizers, etc. The motive power employed is largely electric, there being sundry hydro-electric plants fairly convenient to supply such power and much cheaper than steam power. This chapter also presents costs of labor, amount of power, percentage of fibre to the rock mined, etc., all of which are of interest and value. This subject of costs is further elaborated in Chapter V, which gives also markets and prices with other statistics, and the status of the industry.

Chapter VI treats of asbestos mines and prospects, listing the various properties, giving comparisons of their special features and out-put, location, etc. This information naturally belongs to such a report as this issued by the Mines Department.

Chapter VII is of interest, presenting as it does an account of asbestos in foreign countries—that is to say, elsewhere than in Canada. From these statements it can be readily seen what an important factor of the world's supply, whether in quantity or quality, is that obtained in Canada; and also of what great value to the wealth of the Dominion are these products.

Finally Chapter VIII, of over 40 pages, gives the commercial application of asbestos, with many illustrations of the objects and materials in which asbestos plays an important part.

SURVEY OF NORTHERN AND NORTHWESTERN LAKES. Bulletin No. 20 for 1911, Published by the U. S. Lake Survey Office, Detroit. War Department, Corps of Engineers. Also Supplements No. 1, May 23, and No. 2, June 19, 1911.

The information contained in these publications is supplemental to that shown on the charts of the Great Lakes, which are also issued from the Detroit office. The bulletin and supplements are published to inform navigators and others, with detailed information relating to the Great Lakes shore lines and shallows, river and harbor improvements, etc., which extend from the international boundary, at St. Regis on the St. Lawrence River, to Duluth and Chicago, at the heads of the lakes.

The bulletin contains a couple of tables and then an interesting essay on "The Compass and the Magnetism of the Earth," in the lake region. This is followed by "Extracts from the Laws of the United States," relating to river and harbor matters. The bulletin gives some valuable information about the several Great Lakes with detailed descriptions of coast line, harbors, islands, reefs, etc.

For Lake Superior this covers some 60 pages or more. St. Mary's River is treated in a similar manner, with 10 pages of text, and is followed by descriptive matter on Lake Michigan, including Green Bay and the Chicago and Calumet rivers and harbors, which amount to about 115 pages.

Next comes Lake Huron, descriptive matter in detail of 50 pages, and the St. Clair River, St. Clair Lake, and the Detroit River, filling some 16 pages. This is followed by the text pertaining to Lake Erie, of about 69 pages, followed by 6 pages on the Niagara River to Lake Ontario.

Lake Ontario is treated in a similar manner with some 26 pages of text and the book concludes with the St. Lawrence River, 8 pages and a full index. To those who have merely a visitor's interest in the Great Lakes, and still more so to those who live on or near them, there is much interesting and informing reading to be found in this public document.

REVIEW OF NOTES ON SEWAGE DISPOSAL BY C. E. GRUNSKY. Reprint from California State Journal of Medicine, April, 1911.

Mr. Grunsky speaks of modern sewage disposal from the standpoint of odor, particularly that arising from the use of septic tanks. Two German plants are mentioned, one the plant at Wilmersdorf, where noticeable odor was found from septic sewage, sprinkled on coke beds, the other being the sewage farms of Berlin, with slight odor. Quotations are made from recent reports to show the modern tendency of treating the sewage as fresh as possible, and of using the method of dilution to as great an extent as conditions permit. Mr. Grunsky is of the opinion that as far as most of the cities on the Bay of San Francisco are concerned, the proper distribution of the sewage in the tidal flow will prevent nuisance for many years to come; but that where the discharge is on tide flats extension of the outfalls into deep water or some preparatory treatment will soon be desirable. L. P.

HIGHWAY IMPROVEMENT. I. Construction and Maintenance of Earth, Sand-Clay, and Oiled Roads and Culverts. By W. S. Gearhart, Highway Engineer, Kansas Agricultural College, Manhattan, Kansas. Pam., 6 by 9 in.; pp. 92; illustrated.

This is an excellent essay on country roads, prepared by the State Highway Engineer for distribution through the farming communities of Kansas. It can be read with profit by those interested in highways, in almost all sections of our country. The author very properly emphasizes the necessity of drainage and under-drainage, particularly with prairie roads, and some attention is given to the subject of culverts. Illustrations are presented of culverts built of posts and plank that are defective, a menace to life and limb of those using the road, and of only a temporary character—a wasting of the people's money. Later in the book examples are given with working plans of concrete (plain and reinforced) culverts. If the waterway needed is quite small, these can be made of circular cross-sections by the aid of a central, circular, and collapsible core, which possess decided merits. The expectation is to build such culverts in place instead of using pipe, whether of iron, tile, or concrete, which are brought to the site from elsewhere. In constructing such drains made up of a number of sections of pipe or tile, it is difficult to always maintain a good alignment and grade the whole length of the culvert. Other forms of culverts are those with a flat top slab of reinforced concrete, which have proved very satisfactory. Our old friend the road drag is shown in different forms, and the benefits to dirt roads to be obtained by its use are well set forth.

As implied in the title, the subject of sand-clay roads has been written up, showing the advantages of such road construction, methods of construction, and description of such roads as have been built in different parts of the state.

The subject of oiled earth-roads has also been investigated, and illustrations are given of examples of such roads as have been built and the cost of construction and maintenance. The author frankly says an oiled earth-road is not a substitute for a gravel road, nor a solution of the road problem, but it does create conditions of a dirt-road surface superior to such without the oiling.

The essay is well written, full of interest to those at all concerned with our public roads, and merits wide distribution.

STREET PAVEMENT LAID IN THE CITY OF CHICAGO. An inquiry into Paving Materials, Methods, and Results. Report prepared by the Chicago Bureau of Public Efficiency, dated June, 1911.

The Chicago Bureau of Efficiency was organized for the purpose of increasing the efficiency in the municipal service and in this work, to scrutinize the system of accounting, to look into the methods of purchasing materials and supplies, and the letting of contracts, and to furnish the public with exact information regarding public revenues and expenditures, and thereby promote efficiency and economy in the public service.

This pamphlet of 41 pages is one of the results of the work of the Bureau of Efficiency. A Summary and Conclusion are presented in the opening of the report, in which is shown that there is a monopoly in heavy preservative oil used in the manufacture of wood blocks for street pavements. Another point made in this report is the necessity of more careful and rigid inspection of the materials used. "More may be done to lengthen the life of a pavement and secure economies in the actual cost by establishing effective inspection, than in any other way." A modification of the present specifications for asphalt and wood block pavements, using thinner blocks or layers of asphalt when the service is light, as on residential streets, would result in a saving estimated at $200,000. Certain recommendations as to specifications are offered, based on expert examination, that the reviewer considers of first-class importance.

Following the preceding, the report goes on to consider street pavement under the sub-heads of The Subgrade, Stone Curbing, Combined Concrete Curb and Gutter, Concrete-Asphalt Pavement, with its subdivisions of surface mixture and laying the asphalt, and concluding with economies which may be effected. This is followed by other sections on Granite Block Pavement, Creosoted Wood Block Pavement, and Brick Pavement.

The Conclusion of the report relates to Inspection (which the investigation has shown to be bad and inefficient), and also to Development of Statistical Data.

There are some 11 pages devoted to wood block pavement, which contains a good deal of valuable information pertaining to the kind of wood to be used, the chemical and physical characteristics of the impregnating oil, the depth of the block, analyses of creosoted oils, exudation from the blocks, etc.

The pamphlet has been written in a careful manner, is based on the investigations and researches of experts, and is a worthy addition to our technical library. It should be read by engineers and also by that great mass of our population—the intelligent and conservative taxpayer.

REPORT ON CREOSOTED WOOD BLOCK PAVEMENT, in the Central Business District of Chicago. Prepared for the Loop Protection and Improvement Association by Charles K. Mohler, M. W. S. E., Consulting Engineer, Chicago, January, 1911. Pam., 6 by 9 in.; pp. 62. Illustrated.

This report comes in very appropriately when the question of creosoted block pavement is under consideration by so many interests, and when an objection to this form of street pavement has been made so apparent during the warm weather of this summer.

But there are other matters in this report of interest, as design of manhole and catchbasin covers and their frequency in the street, the subject of rails for street-car track, shape of head, particularly when laid in connection with special track, at curves and the like, the surface drainage at street intersections, and finally the narrowness of the roadway in some streets between the curb or sidewalk, and the columns supporting the elevated railroad track of the Loop.

In the Introduction the author enumerates the defects of a great amount of the street pavements of the business district of the city, as

Rough and uneven surface.
Noise from traffic.
Dirt and dust.
Difficulty and expense of cleaning.
Slippery surface of the stone blocks.

A moment's reflection by any one familiar with the situation will show the correctness of these charges. The author offers

REQUIREMENTS OF AN IDEAL PAVEMENT FOR THE DOWNTOWN DISTRICT AS FOLLOWS.

1st. It should have a surface that will give sure footing to animals and a firm grip for motor vehicles, to secure the greatest tractive effort under all conditions.

2nd. It should have a smooth, even, and uniform surface, of such character as to offer the least resistance to vehicle traction.

3rd. It should be durable and possess uniform wearing qualities.

4th. It should be noiseless from the effect of hoof strokes, the wheel contact on the pavement itself or induced rattle and vibration set up in vehicles passing over it.

5th. It is desirable that it should be not only clean itself, but easily cleaned of any refuse or litter coming upon the roadway.

6th. It should require a small amount of crowning, and form a waterproof surface.

7th. It should be easy of repair.

8th. It should be of such character as to give the most satisfactory construction where junctions have to be made with such obstacles as street railways, manhole covers, etc.

9th. The cost should be reasonable

The author of this report, while allowing the defects in creosoted wood block pavements, and that this form of pavement does not meet all the requirements for an ideal pavement as above enumerated, considers it the nearest approach to such that we now have. Experience has shown that if laid in the best manner, with a smooth, even-wearing surface, the life is almost indefinite.

The author recounts sundry changes lately introduced in the specifications for pavements, and also in the matter of catchbasins and covers, manhole frames and covers, etc.

The subject of the concrete foundation for street pavements, etc., is carefully considered by the author, who does not approve of the use of fine screenings and dust in mixing up concrete, but good, sharp sand should be employed to fill the voids of the aggregate. Suggestions are made as to the laying of the pavement, the sandbed under the blocks, the sand and pitch filler, crosswalks, etc., that are reasonable and worthy of consideration.

The Report possesses decided value to municipal engineers generally, as well as the Association to whom it was originally addressed.

HYDROMETRISCHE MESSUNGS VERFAHREN IN DEN VEREINIGTEN STAATEN AMERIKA. By C. E. Grunsky, Dresden, 1910. 50 pp., 12 mo.; illustrated.

This is a descriptive and analytical account of the progress in stream measurements in the United States since 1878. Various methods are described, using floats, current meters, etc. Particular attention is given to the work done on the Sacramento River, in California, in 1878 to 1879, as well as to the methods of the U. S. Geological Survey. The relation of the mean to the surface velocity is discussed. L. P.

THE AUSTIN (TEXAS) DAM. By T. U. Taylor, M. C. E., of the University of Texas. Bulletin of the U. of T., No. 164. December 22, 1910, Austin, Texas. Pam., 6 by 9 in.; 85 pp. and index, 16 half-tone engravings from photographs and 17 engravings from line drawings.

The author of this bulletin was at one time connected with the U. S. Geological Survey, and in that capacity prepared a paper (Water Supply Paper No. 40) early in 1901, just after the failure of the Austin dam. That paper contained very little information on the flow of the Colorado River, but since then many observations have been made and measurements taken of the flow of the river and these have been printed in this publication.

Austin, the state capital of Texas, is on the Colorado River about 200 miles from its mouth at the Gulf of Mexico The drainage area of this river above Austin is some 37,000 square miles, and ranges from the relatively humid region of Austin (with an average rainfall of 32.27 inches per year) to a semi-arid region about the headwaters of the river. The average rainfall for the whole drainage area is about 20 inches annually. From measurements made in 1890 it was estimated that the minimum flow of the river was 1,000 cubic feet per second and on this basis it was assumed that the flow at the Austin dam would develop 14,000 horsepower for 60 hours per week. With the city demands of 2,000 horsepower there should be available for sale a surplus of 12,000 horsepower for 10 hours per day, six days in a week. Subsequent observations showed this expectation was too much, as a considerable amount of water was lost by evaporation from the 3 square miles of the reservoir exposed, and the minimum flow occurred in the hottest part of the summer. The report goes on to state the dates when the decreased flow was less than the demand for power, which reduced the surface of the water above the dam considerably below the crest of the dam; frequent measurement showed that the minimum flow was less than 200 second feet. It is evident that when the amount of water held up by the dam was reduced and the surface consequently lowered, the head available for the water power was considerably lessened. The results were a great disappointment to many of the citizens who had been misled as to the power available, because there was not the minimum flow that had been counted on.

A good many notable hydraulic engineers have been engaged on this work at one time or another, and this report includes some of the reports made by these engineers. It was early in 1890 that Mr. J. P. Frizell made a report on the proposed dam and quotations from his report are set forth in this pamphlet. The estimated cost of the dam amounted to $1,362,781, and the question of issuing bonds to the amount of $1,400,000 was submitted to the voters of Austin, May 5, 1890. The vote was in favor of the enterprise by an overwhelming majority. In the fall of that same year a contract was entered into for the construction of the dam. The structure was to be of masonry, measuring about 1,100 feet long on the crest, to be about 16 feet thick at the crest, and about 60 feet high. The situation was favorable, as the river flows through a narrow gorge with limestone walls, in some places 150 feet above the bed of the stream. The detailed specifications for this dam are given in full and the profile as originally planned and as modified by Mr. J. T. Fanning, who also had a hand in this undertaking, are shown.

An interesting feature of this report is illustrations of cross-sections of Lake McDonald, as the reservoir above the dam was called, showing what enormous quantities of silt collected above the dam, and the necessity of provision being made to sluice out such deposits from time to time that the reservoir capacity be not too greatly diminished. "In February, 1900, there were 43,460,000 cubic yards of water in the main channel of the lake beneath the level of the top of the dam (equivalent to 42.1 feet on a square mile base), and 38.8 feet of silt. Thus 48 per cent of the original storage capacity of the lake was at that time mud, . . . average rate of deposit, on a square mile base, was 5.8 feet per year."

On April 6 and 7, 1900, there was an exceptionally heavy rainfall, which resulted in the water accumulating to a height of over 10 feet above the crest of the dam. Following this great overflow, with a scouring action below the dam, about one-half of the structure was washed out. The many illustrations and text show fully the course of events in this destructive work which also included the destruction of the powerhouse.

This valuable report contains much more of value to hydraulic engineers, including suggested plans for rebuilding the dam. The University of Texas is doing valuable work in placing this information in this form, available for study, and is to be commended for so doing.

THE TESTING OF AUTOMOBILE ENGINES.

The Automobile Club of America, by its Technical Committee, has issued a pamphlet of 32 pages, 6 by 9 inches, describing some of the apparatus and facilities for testing automobiles at their club house in New York City. The pamphlet contains illustrations and descriptions of the apparatus to make tests of complete power units, of carburetors, of ignition devices, and of transmissions. The special device for determining the "torque" and speed of the motive power is simple and efficient, and by this the horsepower of the engine can be readily determined. Other apparatus gives more complete data as to the performance of the engine as to power output and fuel economy. The testing of carburetors—that important adjunct to internal combustion engines—can be made with precision, there being provision for adapting or modifying the variable factors to get comparable results. The Technical Committee has embodied in this little pamphlet instructions and rules governing the making and reporting of the tests.

A certificate of the test made is issued as may be desired, and in accordance with prescribed regulations. This publication indicates that the Automobile Club of America desires to promote original investigation in the development of automobiles, with the object in view of improvement in all ways, of internal combustion engines as motors applicable to vehicles, boats, flying machines, and the like. In so doing, the club is accomplishing a good work, which is to be commended.

The Water Supply of New York City. The Catskill Mountain Water Works, for the Extension of the Water Supply of New York City. Edited and published by the Blaw Collapsible Steel Centering Co., Pittsburgh, Pa. Pam., 6 by 9 in.; pp. 151, with many beautiful engravings.

Though this is a pamphlet published in the interest of the Blaw collapsible forms for concrete work, the text gives much valuable and interesting data pertaining to this mammoth engineering work. The total length of the aqueduct, as shown in one of the tables in this publication, is a little over 92 miles. There are four principal types of construction—"Cut-and-Cover" Concrete Aqueduct; Grade Tunnels; Pressure Tunnels; and Steel Pipe Siphons.

The simplest part of this work, and the least expensive, is the cut-and-cover work. A trench is excavated, largely by steam shovels, which may be in soil, or perhaps in rock. This trench has a bottom width of 30 feet, though less in compact earth and rock, and the depth averages 12 feet. When the bottom of the trench is brought down to grade, the invert blocks of concrete of 15 feet length are built in place, and then the inside and outside forms of metal construction are erected and filled in with concrete. These are of horseshoe form from the invert. The dimensions of the aqueduct are 17½ feet wide by 17 feet high inside. After the concrete has set the forms are removed and it is the collapsible costruction that permits these forms of sheet metal to be readily removed. After this the aqueduct is covered over with earth as a protection, and to restore the general conditions of the country to its original condition. The construction of the Blaw forms is such that curves can be readily introduced where necessary in the alignment of the aqueduct.

The excellent illustrations show quite clearly how the forms are handled, placing them in position and afterwards removing them on the completion of the work.

The subject of grades has been skillfully worked out by the engineeds, with less grades when the cut-and-cover method of construction has been employed, as this work is the cheapest per unit of length. Where necessary to cross deep valleys, pressure tunnels are used, which have a greater gradient, and the greatest fall or slope per unit of length is given to certain steel pipe siphons, because that is the most expensive form of construction. There are some six miles of steel pipe siphons on the line east of the Hudson river. These are 9¾ ft. in diameter, encased in concrete and lined with 2 in. of cement mortar. Grade tunnels are employed, aggregating some 13½ miles for the 24 tunnels to cross mountains and ridges encountered in the route. The longest of these, at Garrison, is 11,430 ft. long. These tunnels are all lined with concrete, and the Blaw collapsible forms, modified from the forms used in the cut-and-cover work, are here employed, the inside forms only being employed.

This book also contains certain official matters, as a list of officers and engineers engaged in the work; a list of contractors engaged, July 1, 1910; a list of contracts in force Oct. 4, 1910, aggregating over $70,000,000; specifications, with information for bidders, and approximate statement of quantities. Altogether, the book is a valuable and interesting statement of this monumental work.

THE BILTMORE FOREST SCHOOL.

This institution is in a class by itself. It is unique in that there is no appropriation nor endowment, but it is supported by the enthusiasm and the tuition fees from a limited number of scholars—43 on July 1, 1911. There is no central administration building with the accessories usually found in schools. The school has been in existence a dozen years or so, as the latest announcement says, "Fourteenth Year, 1911-1912." The corps of lecturers numbers 14, but these are drawn largely from various universities and the U. S. Forest Service. The school resembles the peripatetic schools of the ancients, as the students live out in the forests where the instruction is given, with practice at forestry. At the head of the school is Carl Alwin Schenck, Ph. D., who is also *Oberfoerster* at Darmstadt, Germany. The lectures and writings of Dr. Schenck show in their thoroughness and logical arrangement the mind of the German preceptor.

For the time being this is the only school of purely technical forestry in the United States, and the teaching is with the sole view to the training of practical workers. "All lectures and all school work are meant to convey such information only as is capable of practical application somewhere in American woods. . . . The topics treated in the class room are invariably and immediately worked upon in the woods. This combination of *class work* and of *wood work* necessitates a continuous sojourn of the entire forest school in the forests. . . . The term *forestry* is here so interpreted as to comprise all technical work connected with the forest, . . . notably all timber cruising, logging, and lumbering work at the saw mill and planing mill; all work connected with the inspection, distribution, and sale of lumber." It is necessarily *a training school for lumbermen.* A graduate from Biltmore has the foundation for an honorable and useful life, but some years of practical experience is needed after graduation before he can command a lucrative salary. No one should enter the service unless he is fitted physically and mentally to take up the isolated and outdoor life away from cities, and with enthusiasm for his work, to endure the hardships which will be met from time to time. Yet there is a growing demand for the services of men properly endowed and trained for such work. Of 107 Biltmore graduates there are 30 in the U. S. Forest Service, 8 others are engaged in State Forestry, and 69 are in private employment.

The opinions held by the Biltmore Forest School faculty in regard to the school are:

1—It must be more practical and technical than scientific.

2—It must be a lumberman's school, or a school for employees of owners of timber lands who look ahead into and plan for the future.

3—It must be a small school, so the students may be in continuous and personal touch with the instructors, notably in the field work.

4—The school must live in the forests continuously, and preferably where the woods are of a diversified character, exhibiting a variety of economic and sylvic conditions. The instructors should have had practical experience in the charge of forests and plantations; in lumbering operations and with saw mills, etc. The sign of a good forest school lies in the willingness of its graduates to brave hard work; in the efficiency when employed in hard work; in their knowledge of men, and knowledge of affairs.

The Biltmore Forest School holds to the belief that forestry must be taught in the forests, and to secure the broadest training in this work the fields of study are diversified. Lumbering, timber cruising, engineering, and saw mill work can be well studied in this country in the southern forests, in the lake states, and on the Pacific Coast. But forest planting and development of forests raised by human aid can be best studied in the Adirondacks and in Germany. The school has therefore established a circuit of five distinct headquarters.

During the winter months the school is established at Darmstadt, Germany. This town, the historic birthplace of forestry, is in the midst of forests, pineries of the Rhine valley and hard woods among the hills near by. The forests present themselves in all stages of development, and of a great variety of woods.

During the early part of the spring, upon their return from Germany, the school spends a month in the Adirondacks, at those points where is centered the forestry work of the state of New York, and where there are large plantations of conifers, cutover woodlands, and primeval forests. The logging and associate activities of lumbering companies in the neighborhood are here studied.

Later in the spring and early summer the school is in the neighborhood of Biltmore, N. C., in the southern Appalachian region. Within this region, depending upon altitude, may be found forest conditions similar to the Gulf states (except the coastal pine belt), the middle Atlantic states, and the northern New England states. The altitude ranges from a broad plateau at 2,300 feet above sea level to 5,000 to 6,000 feet above sea level in the mountainous portions. This gives a great range of varieties and working conditions.

Late summer is spent by the school in the lake states. Logging and milling operations in hard woods, hemlock, and pine are studied at large logging camps, such as in the neighborhood of Cadillac, Mich. In such places the influences of fire, taxes, and the tariff on forestry are studied.

Finally, in the fall of the year the school is encamped in the giant forests of the Pacific Coast, where Douglass firs, spruces, cedars and hemlocks of enormous size compose the forests.

The course of study and work occupies one year, and without any vacation. About five months are spent in Germany; one month in the Adirondacks, about three months in the southern states, and a like amount of time in the lake states and on the Pacific Coast. The expense of such a year of study, work, travel, books, living, and incidentals, with tuition fees, sums up to $1,100, which is very moderate in the opinion of the writer, considering all that is to be obtained by the student.

BULLETINS ON FORESTRY.

FOREST MENSURATION. By Dr. C. A. Schenck, Director Biltmore Forest School, and Forester to the Biltmore Estate. Pam., 6 by 9 in.; 71 pp. The University Press of Sewanee, Tenn., 1905. Price, $1.00.

The Preface states that this pamphlet treats on Forest Mensuration from a scientific mathematical standpoint as well as the viewpoint of practical application. From the book has been omitted lengthy explanations of a mathematical nature, it being the intention that such are to be supplied as may be necessary by the instructor in the course of his lectures. But the book is intended to assist the students at the Biltmore School, containing as it does the teacher's dictation, and thus save the students the necessity of taking down such data during the progress of the lecture.

With the advancing prices of lumber and consequent high prices for stumpage, the owner of woodland will consider under many circumstances the advisability of forest husbandry. Financially considered, a proper outcome of forest husbandry is and must be based on a proper application of the theories and principles involved in forest mensuration. This may be divided into the following:

I. Determination of volume of trees cut down, of standing trees, and of forests.

II. Determination of age of trees and of forest.

III. Determination of increment of trees and of forest.

IV. Determination of sawn lumber, and

V. Determination of stumpage value.

The unit of volume of a tree, or tree section, is based on scientific measurements if exact results are wanted, but for practical purposes, there are varying ways in use among lumbermen, based on some few partial measurements supplemented by local usage which give results in one or another local units, as cubic feet, feet board measure, cords, etc. The shape of a tree trunk is not a cone nor cylinder, but is rather a complex form which may be in part a paraboloid, in part a conoid, and sometimes a cylinder; but it is very seldom that a cross-section of the trunk at any point is truly circular, and seldom does the center of the approximate circular cross-section coincide with the axis of the tree. Rules and formulæ are given for determining the volume of the tree trunk, based on certain measurements. The measurement of the length of logs is simply by means of a tape-line or rule, but the usage varies in different sections as to the lengths into which the logs are cut and generally an extra length is allowed over the nominal length to provide for trimming, bad ends, etc. Various instruments have been devised for measurement of diameters of logs, as log calipers, measuring sticks, etc. It is to be noted that the cubic content of a log will not yield the corresponding feet board measure (1 square foot and 1 inch thick) because of the loss by the kerf of the saw, the loss from edging the boards, the loss from irregularities of the outline of the longitudinal section of the log on its axis, and also the probable defects at the heart of the log. The loss from the saw kerf is greatest with the smaller sizes and varies from 27 per cent to 76 per cent, according to the size of the log and the table employed. This is shown in a table on page 9 and refers to logs 12 feet long cut into boards 1 inch thick. Other rules are presented pertaining to stacked wood, cordwood, bark, etc.

Section II relates to volume of standing trees with instructions and hints how this may be obtained, and how to make the proper measurements. Hints are given to assist in making estimates based on a more or less exact measurement of selected trees.

Other parts of this book relate to the age of trees and of the forest. Also, the increment, whether of height or volume of the trees and whether annual or periodic; also of the forest or tract as a whole and the increment in value. This book should be of great value to the forester, whether in practice or as a student.

BILTMORE LECTURES ON SYLVICULTURE. By Dr. C. A. Schenck, Director Biltmore Forest School, and Forester to the Biltmore Estate. Pam., 6 by 9 in.; 185 pp., including index. Brandon Publishing Co., Albany. Price, $2.00.

Chapter I, with an Introduction, gives the Foundations of Sylviculture, explains the ecological factors and the inter-relation of these and sylviculture, with special relation to North American Sylvia, followed by definitions and explanations. An interesting section is Dr. Henry Mayr's fundamental principles of sylviculture.

Chapter II contains the lectures under the heading The High Forest, which treats on its genesis, the seed, preparations for planting, securing and preparing the seeds, the planting season for, and auxiliaries, instructions for planting seeds of different classes of trees and their subsequent care, transplanting, tools, etc., and cultivation. These instructions are detailed and practical. Other sections of this same chapter pertain to later operations in the high forest, as weeding, thinning, pruning, underplanting, etc. A final section on high forest by species is very valuable as a compendium of species with characteristics of growth, value, etc.

Chapter III relates to The Coppice Forest, which means such a growth of trees as may be had from stump shoots, or by root suckers, layers, or cuttings. This manner of obtaining forest growth is somewhat limited to such varieties of trees which can be so propagated, but otherwise it possesses some decided advantages.

The final chapter of this collection of valuable and instructive series of lectures relates to Forest Products other than Wood and Timber. Anyone interested and practicing sylviculture should have this book as a *vade mecum.*

FOREST PROTECTION. Guide to Lectures Delivered at the Biltmore Forest School by Dr. C. A. Schenck, Director. Pam., 6 by 9 in.; 159 pp. The Inland Press, Asheville, N. C. Price, $1.50.

This valuable treatise was printed pre-eminently for the benefit of the students at this unique school of forestry. In forestry, in this country, the most important duty is the suppression of forest fires. If such can be prevented a second growth will follow such removals made by the forester or lumberman and such second growth would have a definite prospective value. The prospective forest is the forest of the future, but fire destroys such prospective forests.

Forest Protection is divided into the following: Part A, Protection Against Organic Matter, as man, animals, and plants. Part B is protection against inorganic nature, as adverse climatic influence, as heat, frost, and snow and sleet, and protection against storm, erosion, sand drifts and noxious gases. The first protection, against man, is that of adverse possession. To secure this is continuous and notorious possession of all the land. This is secured by careful survey with proper marks, survey monuments, fences, lanes, and the like. The forester should endeavor to straighten out the boundary lines by purchase or exchange. It is better to substitute a natural boundary for an artificial one, the marks, line stakes, or monuments of which can be moved. Next in importance to protection against man is the protection against forest fires which result from the action of men, not always from evil intent, but frequently from carelessness, as from locomotive sparks, from camping parties and the like. Forest fires may be surface fires, underground fires, and top fires. The damage from fires is not only from the loss of standing timber but also the loss of prospective values, as the destruction of seedlings, etc., the destruction of humus and the weakening of the trees, if not destroyed, rendering them more susceptible to the action of insects, fungus growths or the weakening of the tree to the load of snow or sleet.

Some of the factors influencing the amount of damage from a forest fire are the age of the woods; aspect of the slope; severity of the wind and its direction, whether up or down hill; the season of the year, the sylviculture system, and the species of trees forming the forest. The measures taken against forest fires are of a preventive or remedial nature, but above all is the unceasing patrol of the forest during dry weather to extinguish at once any beginning of a fire, however small. Remedial measures are enumerated at some length and then the author considers the treatment of injured woods. To reduce the loss to the owner, the timber of a burned district should be marketed as soon as possible after the fire has been extinguished, and this means permanent means of transportation connecting the forest with a ready market.

Chapter II, Protection Against Animals, includes domestic animals on pasture and their relative injuries; also wild animals, large and small, and birds. But perhaps the hardest foe to combat in the protection of the forest is that of insects. This part of the subject has received a good deal of attention from the author, who presents a very complete life history and analysis of these pests. To properly appreciate and understand this part, the forester needs to have a good working knowledge of forest entomology. There is a valuable reference list of U. S. and state publications which the student should study. Many tables follow showing the family, genus, and species of insects injurious to different varieties of trees, where the injury occurs, and literary references to federal and state publications. It is obvious that the forester must have a working knowledge of botany to appreciate these tables, as the various trees are listed under their botanical names.

Other chapters in this valuable treatise relate to protection of the forest against weeds, which are plants of whatever kind when out of place, also against fungi. Finally the author takes into consideration adverse climatic influences. The conclusion of the book is an "Index to Malefactors," and an "Index of Species Affected."

The book is well written, logical in its arrangement, and is invaluable to a working forester.

FOREST POLICY. By Dr. C. A. Schenck, Director Biltmore Forest School and Oberfoerster in Hesse-Darmstadt. Pam., 6 by 9 in.; 168 pp. C. F. Winter, Darmstadt. Price, $1.75.

This is another of those valuable books in the interest of forestry which is intended primarily for the students at the Biltmore Forest School, but is of interest to all concerned in a truly American forest policy.

As a science this subject covers a vast field and necessarily much of the matter has been drawn from many sources. In the Introduction, forestry is defined with quotations from some eminent writers, as "To ascertain the principles according to which forests shall be managed and to apply these principles to the treatment of forests"; from Schlich's Manual of Forestry. "Forestry comprises the sum total of all knowledge required for the best administration of the forest, with due regard for the interests of the owners in particular and the interests of the commonwealth in general"; from A. Parade's "Cours Elementaire de Culture des Bois." Again, "Constructive forestry is that forestry which increases assets at hand in the woods." "Destructive forestry is that forestry which decreases the assets at hand in the woods." "Conservative forestry is that forestry which retains the assets at hand in the woods." "Forest policy, as a science, has to deal with the role played by the forests and by forestry within the economic system of a commonwealth."

The author has subdivided his text as follows: Under the heading II, The Foundation of Forest Policy, are Characteristic Features of Forestry, and Useful Functions of the Forest. Under III, Statistics, the consumption and production of wood goods, forest areas, and the world's forest wealth, are tabulated. An interesting division is IV, Forest Political History and Forest Political Facts (of about 50 pages), containing a good deal of history, with a table of acreage of national forests; the state forests, and the forest policy of foreign countries. Next comes V, Government Measures Regarding Private Forestry, in which public revenue measures are considered and restrictions are imposed on the owner of forests. This is followed by VI, Government Forestry in Government Forests, and the principles of such administration and control. The final section, VII, is a summation of forest political miscellany, as the National Irrigation Law of 1902, instructions, investigations and statistics, custom duties, and values of exports and imports.

While this book affords interesting reading, it will be still more valuable as a reference book for facts and figures pertaining to forestry.

THE U. S. GEOLOGICAL SURVEY—PROFESSIONAL PAPER NO. 72. Denudation and Erosion in the Southern Appalachian Region and the Monongahela Basin. By L. C. Glen, Washington, D. C., 1911. Pam., 9 by 11½ in.; pp. 137, including index. Five maps and many fine half-tone engravings.

This report is based on an examination made in 1904 and 1905 of the southern Appalachian region and the Monongahela basin in West Virginia, and Pennsylvania in 1907, to note the effect of deforestation and the resulting erosion of the steep slopes.

The area examined was some 400 miles long and from 75 to 125 miles wide—an area of about 35,000 square miles—including part of southwestern Virginia, the western part of North Carolina, the northwestern part of South Carolina, the northern part of Georgia, and portions of northern Alabama and eastern Tennessee.

The examination showed the effect of erosion on the upper portions of the streams, among the mountains and hills, and also showed what enormous volumes of boulders, gravels, sands, and clays had been transported by the streams from their upper reaches down into the major streams, with disastrous consequences to the owners of the properties along the streams. Fertile valleys were covered with the debris, bottom lands were overflowed or washed away, the channels of the streams were choked, and bridges were washed away at times of floods.

The examination covered many miles of the main and tributary streams, 700 miles of the Tennessee River to its mouth, as an example, etc. The main region examined is essentially mountainous, including as it does the Black Mountain range, with Mt. Mitchel that has an elevation of over 6,700 feet, and more than 40 peaks rise above 6,000 feet. For many places the scenery is wild and rugged, as along the Linville, the Doe, the Nantahala, the Tallulah, but along other streams, as the French Broad, the Hiwassee, the Etawah, the Cataba, etc., it is less wild but picturesque and beautiful. The geological age of these mountains is ancient, the rocks being generally metamorphic in character, but they have been exposed to prolonged weathering, with the result that they have been deeply disintegrated or rotted, resulting generally, where not washed away, in a fairly deep residual earth mantle that favors forest growth. Where this disintegrated rock mantle is not washed away, it absorbs the rainfall, to be afterwards given out at lower elevations, as perennial springs, to feed the streams and prevent floods following heavy rains. With the exception of a few high "balds," the mountains were originally covered with magnificent forests, which included a great variety of trees, many of great size. About three-quarters of the area is still forested, but great areas have been denuded by reckless lumbering, forest fires, and the like.

The reviewer finds in this book a corroboration of his own observations in southeastern Kentucky (Whitley county), and across the Tennessee line in the same neighborhood, that the finest growth of poplar, black walnut, white and chestnut oaks, were to be found in the coves and on the northern slopes, while just over the watershed on the southern slopes the soil was drier, less fertile, and with a limited humus floor covering, with the result of small and a more open stand of inferior timber trees, such as red oaks and short leaf pines. The average rainfall in the northern and northwestern parts of the region examined is 40 to 50 inches a year, but on the southeastern slopes of the Blue Ridge the precipitation is much greater, averaging 70 to 80 inches, and the yearly maximum exceeds 105 inches. It is not unusual to have 20 to 25 rainy days in a month, with a precipitation sometimes exceeding 30 inches in 30 days. A table on page 10 gives the average monthly and yearly temperatures and rainfall for ten different points in North Carolina, Tennessee, and Georgia, based on observations for 10 years at Dahlonega, Ga., to 33 years at Knoxville, Tenn. At this latter point the average annual temperature is 57 degrees Fahr., with an average yearly rainfall of 49.7 inches. At Asheville, N. C., this average annual temperature is 55 degrees Fahr., with an average annual rainfall of 42.6 inches.

The population is rather scarce—about 30 to 40 per square mile as an average for the whole region—but generally transportation throughout a great part of this region is very primitive. There are but few railroads, and the country roads generally through the broken country are poor, or non-existent. The population is largely agricultural, and at the higher altitudes grazing is an important industry. When the slopes are kept in grass, erosion is largely prevented, but steep cultivated slopes quickly lose the good surface soil, down to bare rock. Under the system of cultivation followed it is but a few years until the farm is worn out and abandoned, not from exhaustion of the soil, but its actual removal or erosion by the rainfall. The clearing off of virgin forests to make "new ground" is going on continuously, because of the abandonment of once cultivated fields which have lost the surface soil and have become deeply gullied in the process. Yet there are illustrations showing how more enlightened farming methods are recovering and regenerating the deeply gullied surfaces of the slopes. Lumbering has been active for many years, where the stand was near enough to means of transportation, and is now being steadily pushed back further and further, with the higher value of lumber. With few exceptions, this work is carried on in a wasteful manner, the desire being to secure the largest possible immediate returns without regard for the future, forest fires not infrequently follow the lumbermen's operations, with consequent destruction to other standing timber, or of the young growth that otherwise would reforest the cutover tracts.

One effect of this process of erosion, and the loading of the streams with silt, is the rapid filling up of storage reservoirs, created by dams, for the purpose of water power. There are many water powers available throughout the region, and which have been utilized, but the filling up of the ponds above the dams is a very serious problem. Could the washing down of the hillsides on the upper reaches of the streams be limited, thus lessening the amount of material transported by the streams, it would be of great value to the owners of power plants. But to accomplish this is a serious problem, and difficult to attain. Forestation of the hills would be a great assistance in preventing erosion, but the time required and the cost to do this would be almost prohibitive in many places.

The deforestation of the country is not always due to lumbering or clearing off for farming operations. At and near Ducktown, Tenn., are extensive and valuable copper mines, and in the recovery of this metal from the ores a great deal of noxious and poisonous gases are made, which kill all vegetation that it comes in contact with. Pictures of the effect of this destruction of vegetation and consequent erosion are shown, which are striking examples of the evil effects resulting from deforestation.

This account of the studies by the U. S. Geological Survey is very interesting reading, and the lessons herein shown are applicable to many places along the Ohio Valley and its tributaries.

TRADE CATALOGUES.

THE PEDESTAL PILE, MacArthur Concrete Pile and Foundation Company, Chicago, New York, and Seattle. A book for Engineers, Architects, Owners, and Contractors, describing the Pedestal Concrete Pile and discussing the relative merits of wooden and concrete piles of various type. Pamphlet, 6 by 9 ins., pp. 61; illustrated by many half-tone engravings and with tables of supporting power of piles and soils.

This is an interesting contribution to the literature of concrete work and safe foundations.

The pedestal pile is of concrete, preferably with some reinforcement and is made in place by means of a casing which is first driven into the soil, preferably with a core which is withdrawn after the casing has been driven. Soft, fresh concrete is placed in the bottom of the casing and then expanded by driving down a tapering plug, which forces the concrete out into the surrounding soil, thus giving a greatly enlarged bearing at the bottom of the pile. After this concrete has been sufficiently expanded by this action, the rest of the casing is filled with soft concrete up to the top. Where a group of piles are placed it is frequently advisable to connect the tops of the piles with a bearing slab, to be more or less reinforced, which ties together the tops of the piles and thus gives a good foundation, after the concrete has become set and hard, for the superstructure. The great point of this pile is the greatly increased bearing surface with soft soils to support the load of the superstructure. The results of tests indicate that the device is a good one.

The Vulcan Soot Cleaner. DuBois, Pa. G. L. Simonds & Co., Chicago. Pam., 32 pp.; 6 by 9 ins.; many illustrations.

This pertains to apparatus consisting of pipes, valves, and fittings designed, proportioned, and adapted to boiler installations to clean off the soot from such surfaces as flues and tubes which otherwise would hinder the transmission of heat for the generation of steam. The economy of cleaning the heating surface of steam boilers is well understood as a fact, but the amount of this saving is not so readily determined nor as well known. The cleaning off of the soot is done by jets of steam, applied through the above named system of pipes, valves, etc. The operation of cleaning off the soot does not necessitate the shutting down of the boiler, but can be performed as desired and when considered necessary. From the lists of installation of this apparatus, it would seem to be an acceptable device, that has met with favor among the operators and owners of steam power plants.

The Bruce-Macbeth Vertical Multi-Cylinder Gas Engines, for electric lighting, pumping, and general power purposes, using either artificial, natural or producer gas, or gasoline. The Bruce-Macbeth Engine Co., Cleveland, Ohio. Pam., 6¾ by 10 ins., 32 pages, finely illustrated.

These engines are built with two or four cylinders and range in capacity from 27 H. P. to 80 H. P. on natural gas for the two-cylinder engines, and from 75 H. P. to 350 H. P. on natural gas for the four cylinder engines. The power to be had with producer-gas for the same sizes is somewhat less, say 10% to 20%, owing to the lower thermal value of that fuel. The design, judging from the illustrations, is excellent, and the construction is first-class in all particulars.

The illustrations of installations show the engines used in municipal lighting plants and by manufacturing concerns and make an excellent appearance. There is no question but that as a general statement the gas engine is far superior as a power generator to steam engines, particularly in moderate size units. This is shown in an interesting table of Comparative Fuel Costs of different kinds of power, based on a 100 H. P. unit operating at rated load. This table shows a range from $36.00 per H. P. per year (3,000 hours) with a simple non-condensing steam engine, using bituminous coal at $3.00 per ton, down to $5.40 per H. P. per year (3,000 hours) with producer-gas from Dakota lignite at $2.00 per ton.

The catalogue is to be commended to those interested in generation and use of power.

Aylward Sanitary Iron Catch Basins, Catalogue D, Aylward Sons Company, Iron Founders, Neenah, Wis. Pam., 6 by 9 ins., 19 pages.

This relates to catch basins for use in sewer construction which are made in sections, of standard sizes, which can be readily transported, set in place, and connections made (by pipe if desired) to the sewer. The depths are 6 ft. and 7 ft. and the diameter is 24 in. A top section with a grated inlet to allow the entrance of water from the gutter is provided;

this top is flat to be flush with the street paving or may be higher that the top face corresponds to the sidewalk level. The illustrations also show some extra sections to adjust the top level to the street grade, should that be changed after the basin has been set. These basins can be taken up without damage and used again, which should be an advantage sometimes. The joints of the sections are of socket form and can be made water-tight. This feature, with the smooth interior surface, makes this catch basin sanitary.

The manufacturers also exhibit other castings suitable for use in sewer work, as inlets, manhole and lamp-hole covers and flap-valves. This catalogue is of interest to those engaged in sanitary work.

LIBRARY NOTES.

The Library Committee desire to return their thanks for donations to the Library. Since the last publication of the list of such gifts, the following publications have been received:

MISCELLANEOUS GIFTS.

University of North Dakota:
- General Catalogue, 1910-11. Pam.

Kansas State Agricultural College:
- Highway Improvement. Pam.

Chicago Bureau of Public Efficiency:
- Street Pavement Laid in City of Chicago, an Inquiry into Methods, etc. Pam.
- Electrolysis of Water Pipes in the City of Chicago. Pam.

J. W. Alvord, M. W. S. E.:
- Report on the Enlargement and Extension of the Water Supply and Distribution System of Rockford, Ill., by J. W. Alvord. D. H. Maury, and D. W. Mead. Pam.

C. K. Mohler, M. W. S. E.:
- Report on Creosoted Wood Block Paving in the Central Business District of Chicago, for Loop Protective and Improvement Association. C. K. Mohler. Pam.

D. W. Mead, M. W. S. E.:
- The Flow of Streams and the Factors that Modify it, with Special Reference to Wisconsin. D. W. Mead. Pam.

Governor of State of Oregon:
- 2nd and 3rd Biennial Report of State Engineer, 1907-10. Pam.

Tennessee Geological Survey:
- Bulletins 3, 4, 5, 1910. Cloth.

Colorado Agricultural College:
- Adobe as a Building Material for the Plains, 1910. Pam.

E. E. R. Tratman, M. W. S. E..
- Administration Report of the Railways of India. Bds.
- Water Supply and Irrigation Papers Nos. 256, 263, 265. Pams.
- Journal Cleveland Engineering Society, June, 1911. Pam.
- University of Wisconsin Bulletins No. 425, 428. Pams.
- University of Minnesota, Farm Bulletin No. 110. Pam.
- U. S. Department of Agriculture, Bulletin No. 38. Pam.
- Journal of Railway Signal Association, August, 1911. Pam.
- Superheater Tests, A., T. & S. F. Ry. Folio.
- Cours de Mecanique, L. Guillot, Vol. II. Cloth.

Milwaukee Bureau of Economy and Efficiency.
- The Refuse Incinerator. Pam.

M. C. Clark Publishing Co., Chicago:
  A Treatise on the Design and Construction of Mill Buildings, H. S. Tyrrell. Cloth.
C. L. Strobel, M. W. S. E.:
  Reports of National Monetary Commission. Pams.
R. I. Randolph, M. W. S. E.:
  Surface Water Supply in Illinois, 1908-10. Cloth.
Wm. T. Harris:
  The Erie and Michigan Canal. Pam.
Bureau of Railway Economics, Washington, D. C.:
  Bulletins 1-10, 12-18. Pams.
Scientific Publishing Co., Manchester, Eng.:
  The Testing of Engines, Boilers, and Auxiliary Machinery. W W. F. Pullen. Cloth.

EXCHANGES.

John Crerar Library, Chicago:
  List of Books on History of Science. Paper.
American Society of Civil Engineers:
  Transactions, June and September, 1911. Pams
Metropolitan Water and Sewerage Board, Boston:
  Tenth Annual Report, 1910. Pam.
Victorian Institute of Engineers, Melbourne, Australia:
  Proceedings, Vol. XI. Cloth.
American Institute of Mining Engineers:
  Transactions, 1910. Paper.
Institution of Electrical Engineers, London:
  Journal, May, 1911. Pam.
Louisville Water Co.:
  Annual Report, 1910. Cloth.
Ohio Geological Survey:
  Bulletin, 13; The Maxville Limestone. Pam.
Canada Department of Mines:
  Bulletins 1098, 1110, 1137, 1139, 1170. Pams.
University of Wisconsin:
  Bulletin, 423; City Government by Commission, F. H. MacGregor. Pam.
American Electrochemical Society:
  Transactions, 1911. Pam.
New Jersey State Director of Railroads and Canals:
  Railroad and Canal Reports, 1910. Cloth.
  Illinois Bureau of Labor Statistics:
  29th Annual Coal Report, 1910. Cloth.
American Institute of Architects:
  Annuary for 1911. Pam.
Canadian Society of Civil Engineers:
  Transactions, Oct.-Dec., 1910. Pam.
  Elections and Society Affairs, 1911. Pam.
University of Michigan Engineering Society:
  The Michigan Technic, June, 1911. Pam.
National Fire Protection Association:
  Proceedings of 15th Annual Meeting, 1911. Pam.
Oklahoma Geological Survey:
  Mineral Resources of Oklahoma, 1908. Pam.
  Bulletins 5 and 7. Cloth.
Pacific Northwest Society of Engineers:
  Proceedings, July, 1911. Pam.
Institution of Mechanical Engineers, London:
  .Proceedings, Oct.-Dec., 1910. Pam.

- Rhode Island Commissioner of Dams and Reservoirs:
  - Annual Report, January, 1911. Pam.
- Michigan College of Mines:
  - Year Book, 1910-11. Pam.
- New York Advisory Board of Consulting Engineers:
  - Annual Report, 1910. Cloth.
- New York Public Service Commission, First District:
  - Proceedings, 1909. Cloth.
- Wisconsin Railroad Commission:
  - Various Decisions. Pams.
- Royal Society of New South Wales:
  - Proceedings, Oct., 1909, to March, 1911. 6 Pams.
- New Jersey Commissioner of Public Roads:
  - Annual Report, 1910. Cloth.
- American Institute of Electrical Engineers:
  - Transactions, 1910. 2 Vols. Cloth.
- New York Public Service Commission, First District:
  - Franchises of Electrical Corporations in Greater New York. Pam.
- Association of Transportation and Car Accounting Officers:
  - Proceedings, No. 15. Pam.
- Wisconsin Geological and Natural History Survey:
  - The Inland Lakes of Wisconsin. Cloth.
  - The Fossils and Stratigraphy of the Middle Devonic of Wisconsin. Cloth.
- Connecticut Society of Civil Engineers:
  - Proceedings 27th Annual Meeting, 1911. Pam.
- New Jersey Board of Health:
  - 34th Annual Report, 1910. Cloth.

GOVERNMENT PUBLICATIONS.

- U. S. Geological Survey:
  - Bulletins Nos. 431, 449-50, 452, 457-464, 469, 472-3.
  - Geological Atlas No. 177. Folio.
- U. S. Department of Agriculture:
  - Annual Report of Hawaii Agricultural Experiment Station. Pam.
  - The Use of Underground Water for Irrigation at Pomona, Cal. Pam.
  - Irrigation in California. Pam.
  - Progress Reports, Dust Prevention and Road Preservation. Pam
- U. S. War Department:
  - Tests of Metals, 1910. Cloth.
- U. S. Department of Agriculture:
  - Year Book, 1909, 1910. 2 Vols. Cloth.
- U. S. Bureau of Mines:
  - Sampling and Analysis of Furnace Gases. Pam.
  - Briquetting Tests of Lignite. Pam.
  - Bulletins, 12 and 14. Pams.
  - Technical Papers, 3 and 4. Pams.
- U. S. Department of Commerce and Labor:
  - Standardization of Bomb Calorimeters, May, 1911. Pam.
- U. S. Bureau of Education:
  - Bulletins Nos. 2, 4, 5, 1911. Pams.

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Losses by Death.

Wm. Krames, Kansas City, Mo	April 25, 1911
Adam Comstock, Joliet, Ill	August 16, 1911
W. D. Taylor, Chicago	August 26, 1911

Journal of the
Western Society of Engineers

VOL. XVI OCTOBER, 1911 No. 8

INVESTIGATIONS OF FLOW IN BRICK LINED CONDUITS

John Ericson, M. W. S. E.

Presented April 19, 1911, Before the Hydraulic, Sanitary and Municipal Section.

Some Gaugings to Determine the Hydraulic Elements in Connection With the Flow of Water in the Northwest Land and Lake Tunnel System, Chicago, Ill.

At the completion of the so-called Northwest Land and Lake Tunnels as a part of the Water Works System of Chicago in 1901, the author recognized the opportunity for some hydraulic experiments that if properly conducted ought to add valuable information to the rather meager data on the flow of water in circular brick conduits running full.

Description of Pumping Stations and Tunnel System.

This new system at the time it was placed in service consisted of the following parts: One pumping station located at the intersection of Central Park Avenue and Fillmore Street, and one pumping station located at Springfield Avenue and Bloomingdale Road on the C., M. & St. P. R. R. Each pumping station was equipped with three Worthington, direct-acting, vertical, duplex, triple-expansion pumping engines with a capacity of 20,000,000 gallons per 24 hours each. The plungers of these pumps have a diameter of 34½ in., and the two plunger rods for each plunger have each a diameter of 3½ in. The nominal stroke of the pumping engines is 50 in.

The official tests of the engines at the Central Park Avenue Station were made in September, 1902. The records of these tests give the average effective plunger area as 926.52 sq. in., and the slip of the pumps at the time of the official test was measured and reported as ½ of 1%.

The engines at each of these pumping stations are supplied with water through a system of circular brick tunnels terminating at the Carter H. Harrison Crib in Lake Michigan, about three miles from shore.

From this crib to a shaft located at the intersection of Grand

Avenue and Green Street a tunnel with an internal diameter of 10 ft. conveys the water to this point. From this shaft a branch tunnel with an internal diameter of 8 ft., except for a distance of 850 ft., where the diameter is reduced to 7 ft. 3 in., as will be hereafter described, runs southwesterly to the wet well located in the center of the Central Park Avenue pumping station. The center line of this branch tunnel is on the same elevation as the center line of the 10 ft. tunnel where these tunnels intersect the Green Street shaft.

Another branch tunnel with an internal diameter of 8 ft. extends from the Green Street shaft northwesterly to the Springfield Avenue pumping station. The center line of this tunnel, where it connects with the Green Street shaft, is 11 ft. higher than the elevation of the center line of the 10 ft. tunnel and the Central Park Avenue branch. The distance from the crib along the line of tunnel to either one of the pumping stations is about eight miles.

The various shafts connected with this tunnel system were finished after the completion of the tunnels in a different manner for different sections of the tunnel system. The manner in which this was done is clearly illustrated on Plate III.

The shafts at Keith Street on the Springfield Avenue branch, and at Carroll Avenue on the Central Park Avenue branch of the tunnel system, are gate shafts, the general construction of which is shown on the plate.

The alignment of the tunnels and the location of the crib and pumping stations is shown on Plate I. The profiles of the tunnels are shown on Plate II, and the manner in which the various shafts were completed is shown on Plate III.

In addition to the shaft at the crib and at the pumping stations, four other shafts were left accessible. These shafts, named after the streets upon which they are situated, are Kingsbury, Green (junction of the three arms of the tunnel system), Carroll and Keith (gate shafts).

Each branch of this tunnel system was built by a different contractor, the main tunnel from the crib to Green Street being one contract, the branch tunnel from Green Street to Springfield Avenue pumping station being another, and the branch from Green Street to Central Park Avenue pumping station a third.

In the fall of 1902, Mr. E. P. Scott, an assistant engineer connected with the Bureau of Engineering, was instructed to place gauges in the shafts at Carroll Avenue and Keith Street, gauges having already been placed at Central Park Avenue and Springfield Avenue and outside the shaft in the well at the crib. These gauges were graduated to feet, tenths, and half-tenths. At the pumping stations floating gauges had been placed, but at Central Park Avenue there was also a fixed gauge placed on the wall inside in the suction shaft, and the floating gauge was not used for

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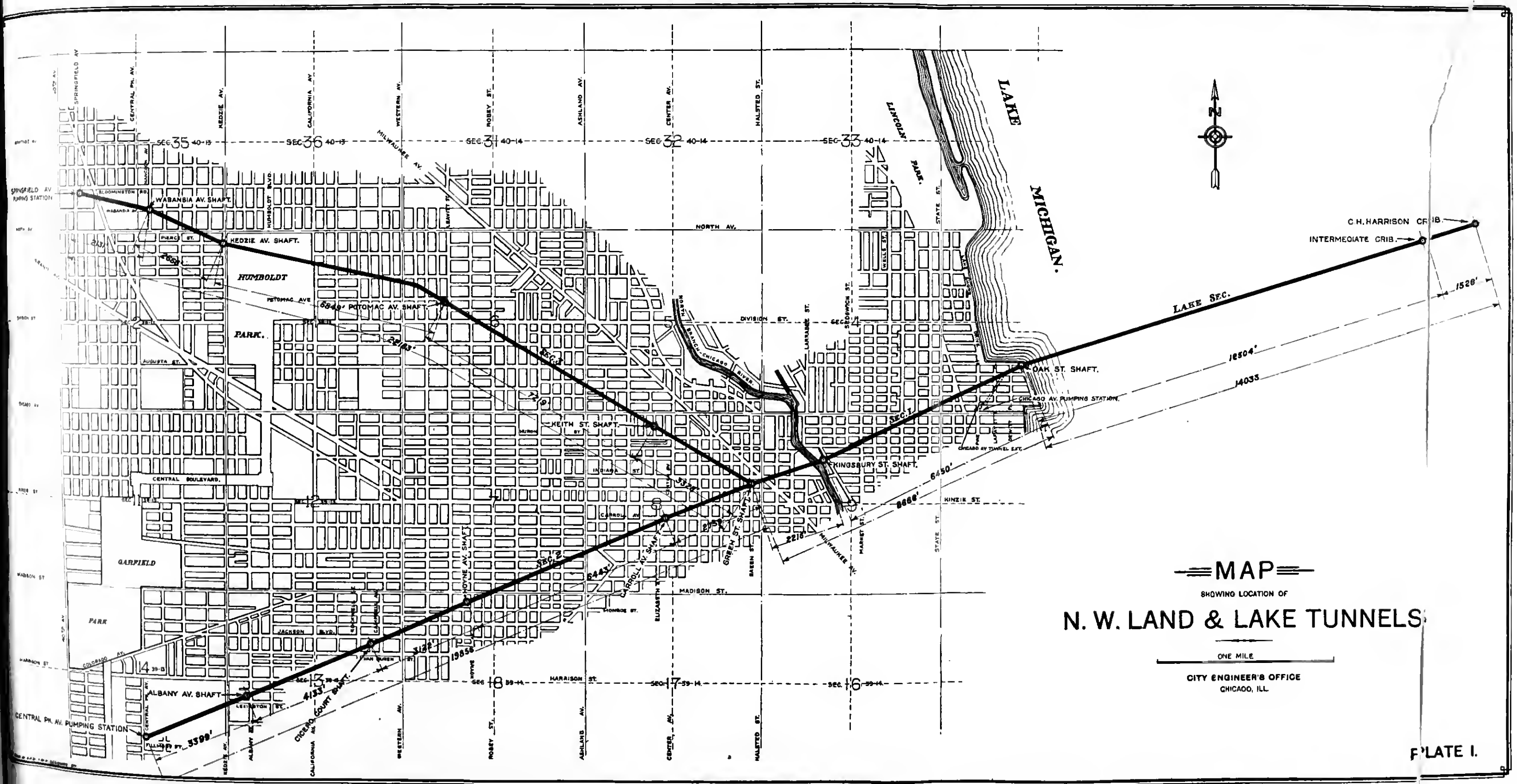

MAP

SHOWING LOCATION OF

N. W. LAND & LAKE TUNNELS

ONE MILE

CITY ENGINEER'S OFFICE
CHICAGO, ILL.

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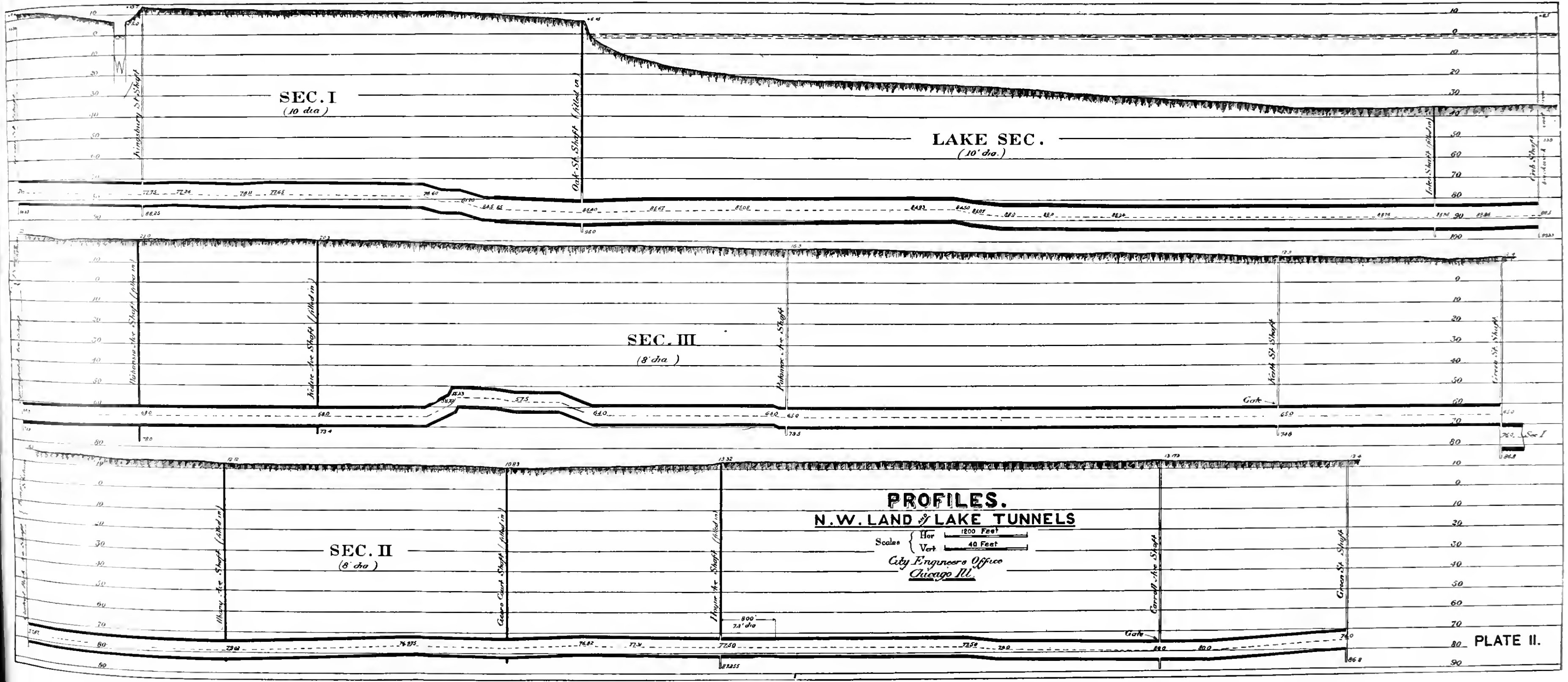

PROFILES.

N.W. LAND & LAKE TUNNELS

Scales { Hor 1200 Feet
Vert 40 Feet

City Engineers Office
Chicago Ill.

PLATE II.

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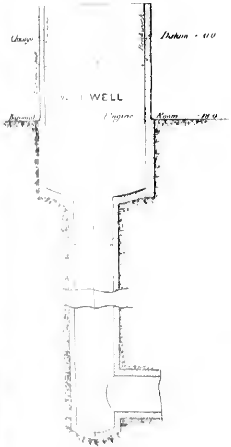
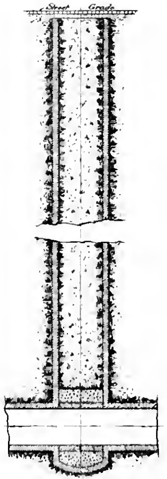
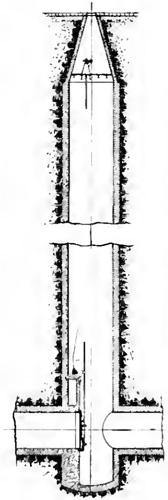


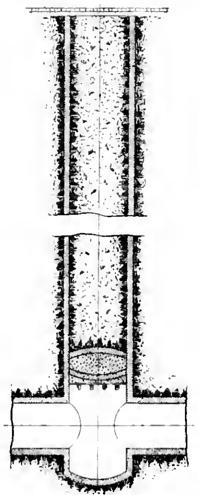
SHAFT AT PUMPING
STATIONS



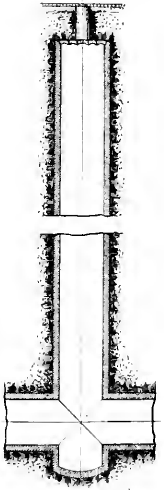
WABANSIA AVE.
KEDZIE
ALBANY
CICERO COURT



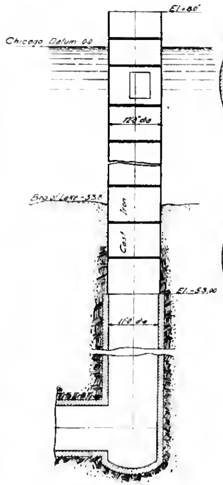
KEITH ST.
CARROLL AVE.



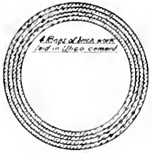
INTERMEDIATE
OAK ST.
HOYNE AVE.



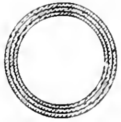
KINGSBURY ST.
GREEN "
POTOMAC AVE.



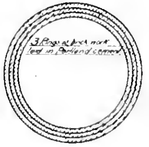
INTAKE SHAFTS



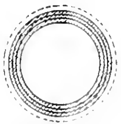
LAKE SEC.



SECS. II&III



SEC. I



SEC. II
Adjoining Hoyne Ave. Shaft

TYPICAL SECTIONS

—TUNNELS AND SHAFTS—

N. W. LAND AND LAKE TUNNELS

CITY ENGINEER'S OFFICE
CHICAGO ILL

PLATE III

these gaugings at this shaft. At Kingsbury Street and at Green Street shafts floating gauges of a type as shown on the sketch were used for the 1902 experiments. The zeros of all these gauges were established by Mr. Scott, presumably at the Chicago City Datum, from the nearest reliable city bench mark in each case.

The plan adopted in placing these gauges was as follows:

The elevation of the two nearest city bench marks in the vicinity of each shaft was first obtained from the City Bench Engineer, W. H. Hedges. Two lines of levels were then run between these bench marks before continuing the levels to a point on the manhole frame over the shaft. This latter line of levels was also run over twice.

The elevation of a point on the manhole frame of the shaft having thus been established, the zero of the board gauges for two of the shafts, which were provided with a gate-lifting gear and platform near the water level, was located by measuring down the wall of the shaft to which the gauge was secured, the distance the point on the manhole frame was found to be above the datum line. For two shafts, Kingsbury and Green, which were not provided with the platform mentioned above, the float and rod here shown were used, so that the readings could be taken at the street level.

Referring to the following sketch, *A* is a wooden frame supporting the board gauge which has a vertical adjustment of 8 in. and held in place by a wing nut and washer. *B* is the rod threaded at its lower end and passes through the wooden float *D* into a threaded flange secured to the under side of the block. The float *D* is 12x15x4 in. pine, and is given a heavy coat of paint to prevent the absorption of the water.

A hole 2½ in. in diameter was bored through this block near its center for the purpose of bringing the water level mark close to the base of the rod. This water mark in the opening was established after the rod had been screwed into position to make the necessary allowance for its weight.

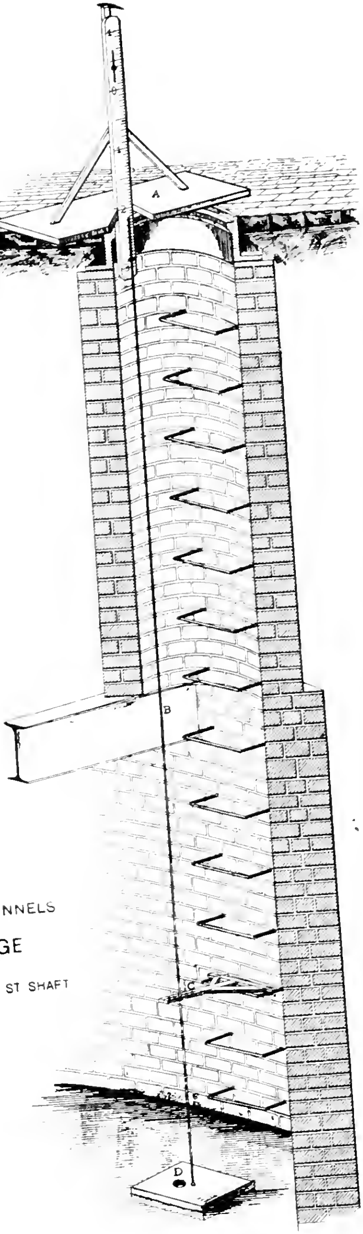
The frame *C* is a guide for the lower end of the rod, and prevents the block from floating off sideways out of the vertical.

The zero of this gauge was fixed at an elevation above datum equal to the length of the rod or the height of its tip above the water. The rod thus communicated the motion of the water to the surface, giving the same results as with the gauge located at the water level.

Gaugings No. 1.

On October 15, 1902, with two engines at Springfield Avenue and three at Central Park Avenue pumping stations in operation, observers were placed at each shaft and the water level read on the gauges every five minutes from 10 o'clock a. m. until 6 p. m., the watches of the observers having all been previously set alike.

The revolutions of the engines were read and recorded regularly. The average strokes of the plungers were for this experi-



N W LAND AND LAKE TUNNELS

FLOATING GAUGE

USED AT

KINGSBURY ST SHAFT & GREEN ST SHAFT

ment assumed at 49½ in., which appeared to be the correct length of stroke.

As the engines at Central Park Avenue station had been tested and were in good condition the previous month, the slip at this station was assumed to be 1½%. At Springfield Avenue, where the conditions were not quite as favorable, the slip was assumed at 2%. From these data the quantity of the flow of water through each 8 ft. branch of the tunnel system was calculated. The quantity flowing through the 10 ft. or main tunnel was taken to be the combined quantities flowing through the two branches.

The average area of the cross sections of the tunnels having been determined by numerous measurements long after forms were removed, the mean velocity V for each section was readily found.

Upon calculating the value of the coefficient C in the formula $V=C\sqrt{R\,S}$, using the data thus obtained, such variable results for different stretches of the tunnel were obtained that it became evident something was wrong.

Gaugings No. 2.

On October 31, 1902, a new set of readings was taken under practically the same conditions as on October 15th, except that this time the stroke of each engine was actually measured every fifteen minutes during the entire time of the test. These observations also failed to give reasonable results.

Gaugings No. 3.

On the following 6th of November a series of readings were taken with only one engine at each station in operation. These observations also extended for a period of eight hours, although only one hour's run as showing the most satisfactory conditions has been selected for the calculations. As much care as possible was used with the implements at hand. In view of the very slight slope of the water from shaft to shaft as a result of this experiment (the average velocity of the water being only about ½ ft. per second), and the very erratic slopes obtained from the gauge readings, it now became evident that the zeros of the gauges were not in one plane. Levels were again run from the bench marks originally used to establish same, and were found practically correct with reference to the bench marks. It was further evident that the given elevations of the bench marks themselves were not with reference to one true plane.

As observations of this character would be of little or no use without a true plane to which to refer all gauge readings, it became evident that some other way than by referring them to zeros of gauges set by level instruments from these bench marks must be adopted if any results of value were to be obtained.

The fact that water seeks its own level was now seized upon. Here we had at our disposal about twelve miles of tunnels, with vertical shafts at either end and at intervals along the line, in which the water could rise and the elevation of its surface be measured.

The difficulty presenting itself was the necessity of shutting down two pumping stations in order to stop the flow of water through the tunnels. As these stations had been but recently put in operation, conditions on account of a temporary shut-down could not be much worse than they had been for years previous, and as the shutting down would occur at night and the pumps could be started on a few moments' notice, no serious results were anticipated.

First Gaugings with Pumps Shut Down

On November 21, 1902, all the pumping engines at both stations were consequently shut down at 10 o'clock P. M. At 10:30 the gates on the shaft at the crib were closed and the water in the tunnel allowed to come to rest. At 11 o'clock P. M. observers at all the shafts were ready and readings were taken every five minutes from that hour until 12:30 A. M. of the 22nd. Small gauges graduated to one-hundredth of a foot had previously been placed in shafts where there were fixed gauges, the zeros of these small gauges corresponding exactly with the zeros of the old gauges. This was for the purpose of obtaining direct readings to one-hundredth of a foot.

It was found that the fluctuations of the water in the tunnel were considerable, the water surface at times varying as much as ½ ft. or more between two readings. It was not thought advisable to keep the pumps shut down for any considerable length of time, and these observations were thrown out as unreliable, except that the results have been platted on Plate VII for an approximate check on the other observations.

Second Gaugings with Pumps Shut Down.

At 10:35 P. M. on the 29th of November the engines were again stopped, and at 11:15 the gates on the crib shaft were closed. The gauge readings were taken from 12 o'clock midnight until 1:30 A. M. and at some shafts for a longer period of time, owing to a misunderstanding on the part of the observers. In this case the maximum and minimum readings were observed for each fluctuation of the water surface, and each reading and time when taken were carefully recorded.

Even the results thus obtained were not considered altogether reliable at the time, and all records were temporarily put aside.

New Gauges Set.

In the spring of 1903 a new set of gauges carefully graduated to one-hundredth of a foot were made and carefully located one in each shaft, fixed gauges replacing the floating gauges at Kingsbury, Green, and Springfield shafts. No effort was spared to fix the zeros of these new gauges so as to correspond to the old gauges placed by Mr. Scott in 1902, and which had been used in previous gaugings.

In April and May, 1903, Mr. W. W. Marr, Assistant Engineer connected with the Bureau of Engineering, ran an elaborate system of levels to each of the shafts mentioned from standard concrete bench monuments. These standard monuments had been established during the previous five years with the utmost possible care by an engineer connected with the Department of Public Works, who had devoted his entire time to this purpose.

A new record of the elevations of the zeros of the gauges was thus again obtained and recorded.

Gaugings No. 4.

In the latter part of July of the same year the engines at both the stations were put in good order, and on July 30th, with all three engines at each station in full operation, a new set of readings was obtained.

The gauge readings were taken every minute for three hours from 1 o'clock P. M. until 4 o'clock P. M. The revolution counters, as well as the strokes of each engine, were read every five minutes during this time, and the results recorded.

Gaugings No. 5.

Owing to some misunderstanding the water gauge at Springfield Avenue station was not read on this occasion, July 30th, and the entire experiment was repeated on the following 7th of August, when similar readings were taken from 1 o'clock P. M. until 4 o'clock P. M.

Nearly a year had now elapsed since the first readings were taken, and all the gauges had been replaced with new ones. A new gauge had also been placed inside the gate shaft at the crib with its zero on exactly the same elevation as the gauge in the crib well, located some distance from the shaft. This inside gauge was, however, set seven-thousandths of a foot higher than a gauge already placed there, and which was found this much in error, being this much lower than the gauge in the well outside the shaft. The elevation of these crib gauges as referred to the Chicago City Datum was established by an extended series of simultaneous readings of these gauges, and gauges placed at different points at the shore of the Lake, which gauges had been connected up by level instruments to the nearest standard bench monument.

It was then decided to make one more attempt to check the relative accuracy of the elevations of the zeros of each one of these new gauges along the whole line of tunnels with the water at rest in the entire system.

Third Gaugings with Pumps Shut Down.

On August 22nd at 10 o'clock P. M. one engine at each pumping station was shut down, half an hour later another engine at each station was shut down, and at 11 o'clock P. M. the third and last engine at each station was shut down. This was done for the purpose of reducing the pendulum motion of the water as much as possible. The crib gates were closed at 11:30 P. M. and then the water in the tunnels was allowed three hours and a half to come to rest. The watches of all the observers were set alike, and from 3 o'clock until 4 o'clock A. M. on the 23rd of August readings at half minute intervals were taken. The variation of the water level during this period was very slight, and the results obtained were considered very accurate. The slight variation in the height of the water noticed is ascribed to the leakage of the water through the gates at the crib, as the water in the well varied, the shaft gates not being very tight.

The gauge readings of all these experiments have been platted and are herewith appended as Plates IV, V, and VI. One interesting feature to be observed on these diagrams is the seemingly simultaneous rise and fall of the water in the shafts along the whole line of tunnel.

The averages of the readings for corresponding periods and periods of different lengths of time for each shaft have been carefully analyzed, and the most apparently correct values determined. The averages of all the gauge readings taken each day were used for gaugings Nos. 1, 2, 4, and 5.

Referring to Plate VII it will be seen that the location of the zero of gauges as determined from water-level readings of November 30, 1902, and those determined from readings of August 23, 1903, correspond remarkably well, except at Kingsbury Street where the zero of the gauge as determined by the water-level readings of August 23, 1903, is at an elevation of fifty one-thousandths of a foot, or one-half tenth higher than the zero of the gauge as determined approximately by water-level readings of November 21st and November 30, 1902, and precisely with reference to the gauge at Green Street shaft, by careful leveling by Mr. W. W. Marr, who connected these two shafts by instrument levels.

As the floating gauge at this shaft was replaced in April, 1903, by a fixed gauge, it is evident that in measuring down the shaft the fixed gauge was placed with its zero fiftyone thousandths of a foot, or one-half tenth higher than the relative zero at which the floating gauge was set, and this has been taken to be a fact.

The very small variations at two or three of the other shafts (at Keith Street three-thousandths of a foot, at Green Street two-thousandths of a foot, and at the crib fifteen-thousandths of a foot) are easily explained by the fact that the fluc-

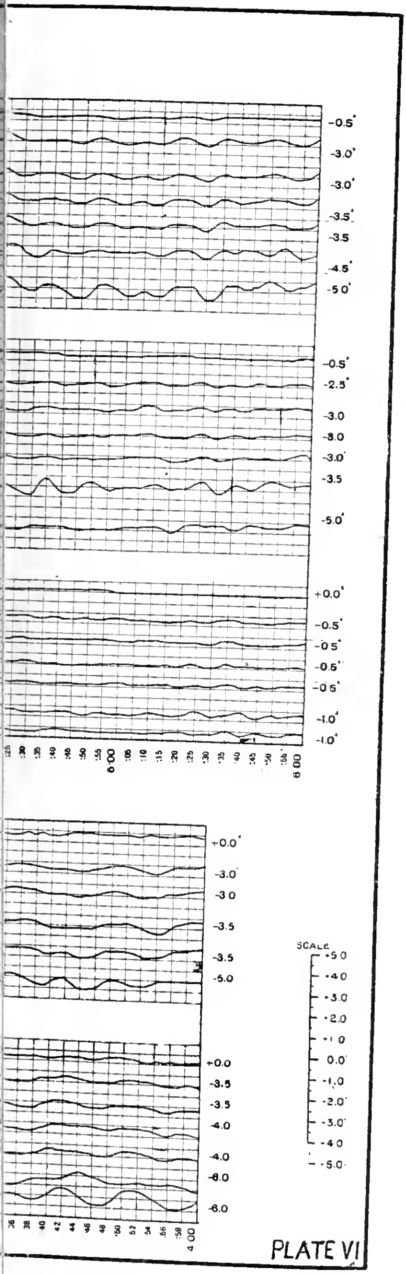
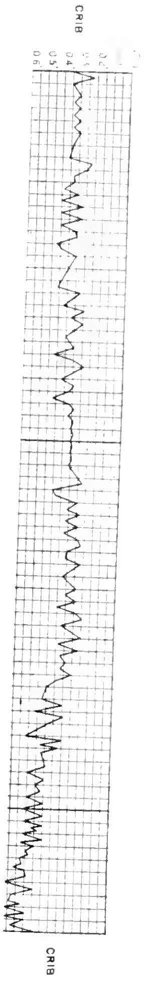


PLATE VI

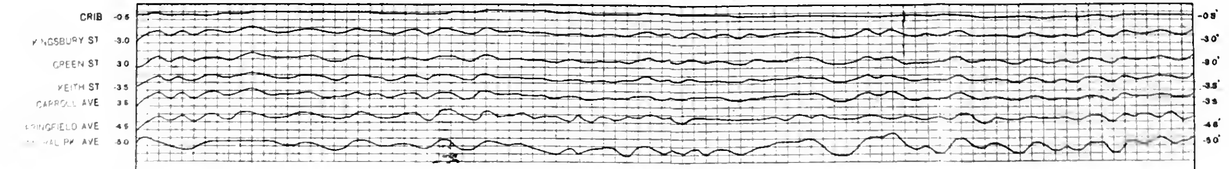


N. W. LAND & LAKE TUNNEL
WATER LEVEL READINGS
NOVEMBER 30TH 1902. 12 TO 2.20 A M

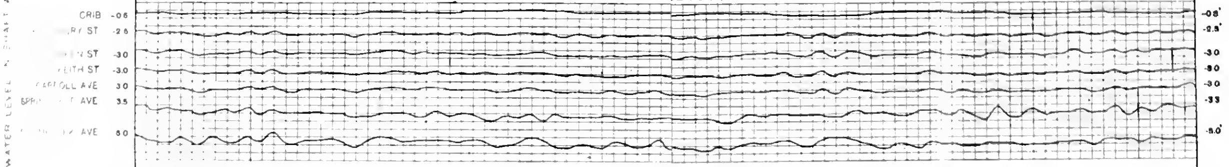
664 a.

N W LAND AND LAKE TUNWATER LEVEL READINGS

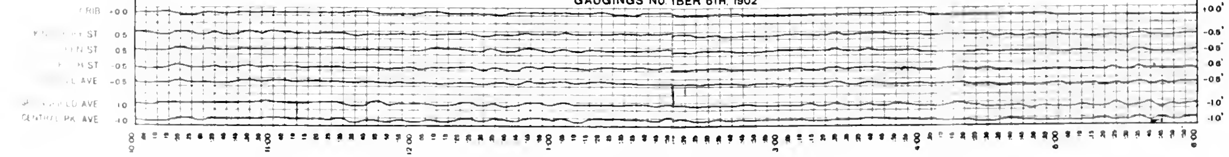
GAUGINGS NO.ER 15TH. 1902



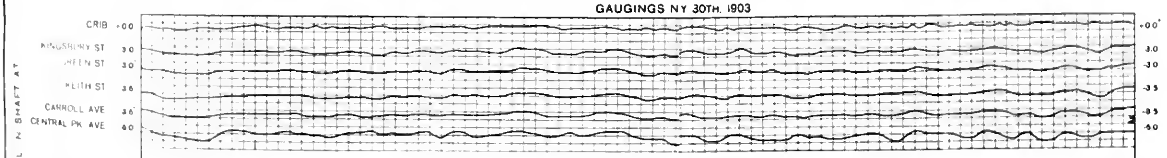
GAUGINGS NO.BER 31ST. 1902

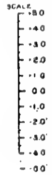


GAUGINGS NO. 1BER 6TH. 1902



GAUGINGS N.Y 30TH. 1903





GAUGINGS NO.IST 7TH. 1903

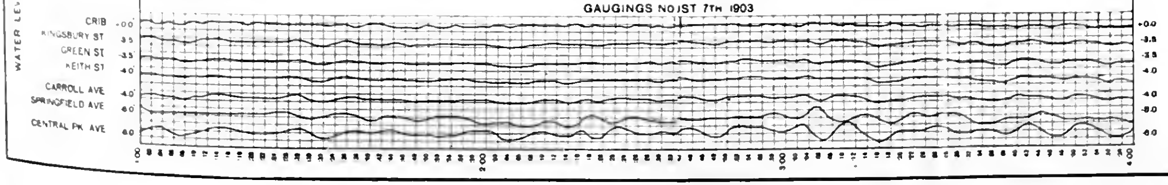
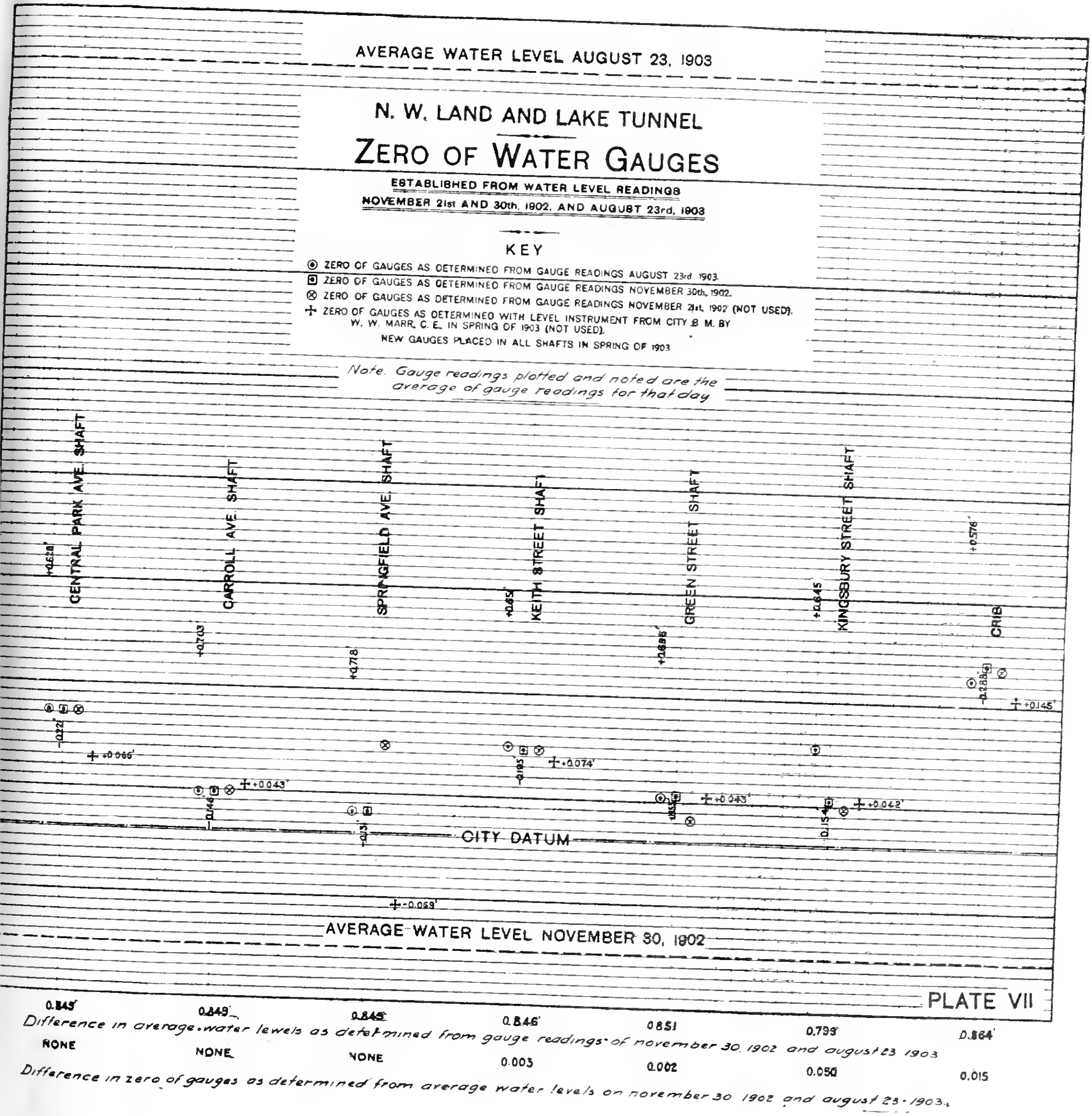


PLATE VI



AVERAGE WATER LEVEL AUGUST 23, 1903

N. W. LAND AND LAKE TUNNEL

ZERO OF WATER GAUGES

ESTABLISHED FROM WATER LEVEL READINGS
NOVEMBER 21st AND 30th, 1902, AND AUGUST 23rd, 1903

KEY

- ⊙ ZERO OF GAUGES AS DETERMINED FROM GAUGE READINGS AUGUST 23rd 1903.
- ⊡ ZERO OF GAUGES AS DETERMINED FROM GAUGE READINGS NOVEMBER 30th, 1902.
- ⊗ ZERO OF GAUGES AS DETERMINED FROM GAUGE READINGS NOVEMBER 21st, 1902 (NOT USED).
- ✛ ZERO OF GAUGES AS DETERMINED WITH LEVEL INSTRUMENT FROM CITY B. M. BY W. W. MARR, C. E., IN SPRING OF 1903 (NOT USED).

NEW GAUGES PLACED IN ALL SHAFTS IN SPRING OF 1903

Note. Gauge readings plotted and noted are the average of gauge readings for that day

0.845' 0.849' 0.845' 0.846' 0.851 0.795' 0.864'

Difference in average water lewels as determined from gauge readings of november 30. 1902 and august 23 1903

NONE NONE NONE 0.003 0.002 0.050 0.015

Difference in zero of gauges as determined from average water levels on november 30 1902 and august 23 1903.

Third G

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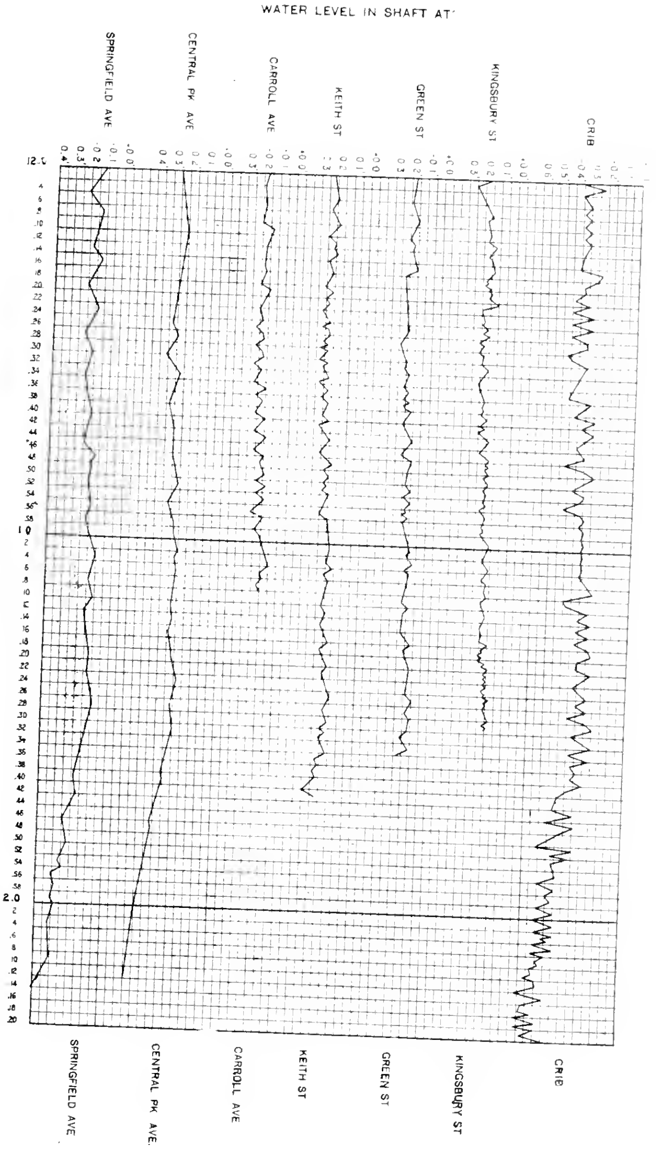


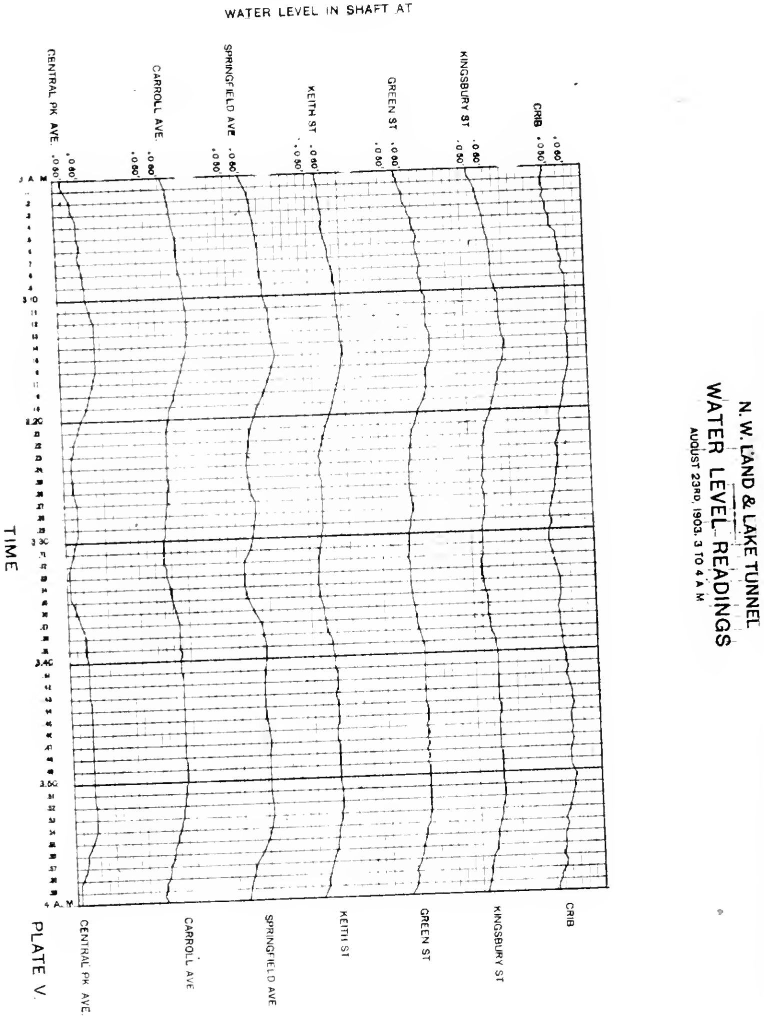
N. W. LAND & LAKE TUNNEL

WATER LEVEL READINGS

NOVEMBER 30TH. 1902. 12 TO 2.20 A M

PLATE IV.

tuations of the water surface at the time of the November 30th experiment, especially at the crib (see Plate IV), and the difficulty in reading the maximum and minimum water level and the time simultaneously and correctly made such small errors quite possible. The locations of the zeros of the gauges,



N. W. LAND & LAKE TUNNEL
WATER LEVEL READINGS
AUGUST 23RD, 1903. 3 TO 4 A.M.

PLATE V.

except the gauge at Kingsbury Street for gaugings Nos. 1, 2 and 3, as determined from the experiments of August 23, 1903, and which are considered very accurate, have been taken as correct:

The relative elevation of the zeros of gauges as determined by level instrument from standard concrete bench monuments by Mr. Marr, while not used in these calculations, have been indicated on Plate VII by crosses.

The datum plane to which these instrument elevations have been referred is assumed, being determined by taking the Green Street gauge elevation as correct.

One of the conclusions to be drawn from these experiments is that bench marks which are considered reliable by the Bench Engineer, and even the so-called precise standard bench monuments, are not altogether correct as regards their established elevations. The small variations noted may be due to settlements or other disturbances or causes.

Previous to the experiments of July 30 and August 7, 1903, the pumping engines were put in good condition. It was not expected that they were quite equal to their condition in the fall of 1902, and the slip was assumed at 3%, which is probably very nearly correct.

It was the hope and intention of the author to supplement the results of these experiments by additional ones as soon as a fourth engine had been installed at each pumping station, in order to obtain a wider range of the velocity of the water in the tunnels and a greater slope of the water surface, in which case the results would be more valuable and any small errors would not affect the results as much as with smaller velocities and slopes. Before these fourth engines were installed, however, it had become necessary to leave the connection between this system of tunnels and the Chicago Avenue system permanently open, and the tops of all the shafts had been concreted and paved over so that any further attempts at gaugings have been abandoned, at least temporarily. This will partly explain why such a long time has elapsed between the making of these experiments and the presentation of the final results.

The general data for each gauging, as well as a tabulation of results, are presented herewith, so that those interested can make their own calculations under various assumptions. All the log sheets and detail data have been preserved by the author, who will, if required, place the same at the disposal of those especially interested.

ANALYSIS OF RESULTS.

Section Crib-Kingsbury. This section consists of a circular brick tunnel with an inside horizontal diameter of 10 ft. and a vertical diameter of 10 ft. 2 in. These dimensions are more or less reduced under pressure after the forms are removed, and actual measurements were taken to obtain the average area of cross section. The length of this section is 20,483 feet. There is an abrupt bend at the bottom of the crib shaft and two enlargements where some of the filled shafts intersect the tunnel.

GAUGINGS NO. 1

DATE October 15, 1902.

SHAFT	Average Gauge Readings	Corrections Nov. 30 Read'g	Corrections Aug. 23 Read'g	Corrected Readings	Head H	Corrected Head h_5	OBSERVER
CRIB	-0.127	+0.120		-0.007			Dan'l Donavan. Well. Gauge at Crib used.
KINGSBURY ST.	-2.303	-0.001		-2.304	2.297	2.050	John A. Lennartson
GREEN ST.	-2.506	+0.000		-2.506	0.202	—	W. W. Marr
KEITH ST.	-2.715	+0.045		-2.670	0.164	—	R. A. Stokes.
SPRINGFIELD AV.	-3.646	-0.022		-3.668	0.998	—	Richard Bow.
CARROLL AV.	-2.829	-0.007		-2.836	0.330	—	T. Frank Quilty.
CENTRAL PK. AV.	-4.987	+0.068		-4.919	2.083	—	Martin Zatterberg.

$H = h + h_1 + h_2 + h_3 + h_4 + h_5$

h = velocity head = 0.057
h_1 = entry head at gates = 0.12
h_2 = entry head at tunnel = 0.03
h_3 = head due to enlargement = 0.04
h_4 = head due to contraction = negligible
h_5 = friction head

PUMPAGE

SPRINGFIELD AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches	REMARKS
No. 1	8	8369	49.5"	Net area of plungers 926.52 sq. in.
No. 2	—	—	—	
No. 3	8	8126	49.5"	

Total pumpage = 1.751.171.0 cu. feet.
Less slip 2 % = 35.023.0 cu. feet.
Total = 1.716.148.0 cu. feet.

Flow in cu. feet per second = 59.59
Average area of tunnel section = 51.35 sq. feet.
Mean velocity = V = 1.160 ft. per sec.

PUMPAGE

CENTRAL PARK AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches.	REMARKS
No. 1	8	8607	49.5"	Net area of plungers 926.52 sq. in.
No. 2	8	8514	49.5"	
No. 3	8	8598	49.5"	

Total pumpage = 2.730.425.0 cu. feet.
Less slip 1½ % = 40.956.0 cu. feet.
Total = 2.689.469.0 cu. feet.

Flow in cu. feet per second = 93.39
Average area of tunnel section = 50.95 sq. feet.
Mean velocity = V = 1.830 ft. per sec.
Mean velocity = V = 2.140 ft. per sec. in contracted section.

CRIB TO GREEN STREET

Flow in cu. feet per second = 152.98
Average area of tunnel section = 79.12 sq. feet.
Mean velocity = V = 1.933 ft. per sec.

GAUGINGS NO. 2

DATE October 31, 1902.

SHAFT	Average Gauge Readings	Corrections Nov. 30 Read'g	Corrections Aug. 23 Read'g	Corrected Readings	Head H	Corrected Head h_5	OBSERVER
CRIB	-0.146	+0.120		-0.026			Dan'l Donavan. Well Gauge at Crib used.
KINGSBURY ST.	-2.529	-0.001		-2.530	2.504	2.243	John A. Lennartson
GREEN ST.	-2.746	+0.000		-2.746	0.216	—	W. W. Marr.
KEITH ST.	-2.995	+0.045		-2.950	0.204	—	W. Strippelman.
SPRINGFIELD AV.	-4.059	-0.022		-4.081	1.131	—	Richard Bow.
CARROLL AV.	-3.087	-0.007		-3.094	0.348	—	T. Frank Quilty.
CENTRAL PK. AV.	-5.383	+0.068		-5.315	2.221	—	Martin Zatterberg.

$H = h + h_1 + h_2 + h_3 + h_4 + h_5$

h = velocity head = 0.06
h_1 = entry head at gates = 0.13
h_2 = entry head at tunnel = 0.03
h_3 = head due to enlargement = 0.04
h_4 = head due to contraction = negligible.
h_5 = friction head

PUMPAGE

SPRINGFIELD AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches	REMARKS
No. 1	8	8278	49.61	Net area of plungers 926.52 sq. in.
No. 2	—	—	—	
No. 3	8	8336	49.25	

Total pumpage = 1.761.288.0 cu. feet.
Less slip 2 % = 35.226.0 cu. feet.
Total = 1.726.062.0 cu. feet.
Flow in cu. feet per second = 59.93
Average area of tunnel section = 51.35 sq. feet.
Mean velocity = V = 1.170 ft. per sec.

PUMPAGE

CENTRAL PARK AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches	REMARKS
No. 1	8	8945	49.614	Net area of plungers 926.52 sq. in.
No. 2	8	8989	49.704	
No. 3	8	8968	49.636	

Total pumpage = 2.864.753.0 cu. feet.
Less slip 1/2 % = 42.971.0 cu feet.
Total = 2.821.782.0 cu. feet.
Flow in cu. feet per second = 97.98
Average area of tunnel section = 50.95 sq. feet.
Mean velocity = V = 1.923 ft. per sec.
Mean velocity = V = 2.341 ft. per sec. in contracted section.

CRIB TO GREEN STREET

Flow in cu. feet per second = 157.91
Average area of tunnel section = 79.12 sq. feet.
Mean velocity = V = 1.996 ft. per sec.

GAUGINGS No. 3

DATE, November 6, 1902.
2 to 3 P.M.

SHAFT	Average Gauge Readings	Corrections Nov. 30 Read'g	Corrections Aug. 23 Read'g	Corrected Readings	Head H	Corrected Head hs	OBSERVER
CRIB	+0.131	+0.120		+0.251			Dan'l Donavan Well Gauge at Crib used.
KINGSBURY ST.	-0.224	-0.001		-0.225	0.476	0.418	John A. Lennartson
GREEN ST.	-0.255	+0.000		-0.255	0.030		W. W. Marr.
KEITH ST.	-0.380	+0.045		-0.335	0.080		W. Strippelman.
SPRINGFIELD AV.	-0.696	-0.022		-0.718	0.383		Richard Bow.
CARROLL AV.	-0.307	-0.007		-0.314	0.059		T. Frank Quilty
CENTRAL PK. AV.	-0.623	+0.068		-0.555	0.241		Martin Zatterberg.

$H = h + h_1 + h_2 + h_3 + h_4 + h_5$

h = velocity head = 0.01
h_1 = entry head at gates = 0.02
h_2 = entry head at tunnel = 0.008
h_3 = head due to enlargement = 0.02
h_4 = head due to contraction = negligible.
h_5 = friction head.

PUMPAGE

SPRINGFIELD AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches.	REMARKS
No. 1	—	—	—	Net area of plungers 926.52 sq. in.
No. 2	1	1089	49.762	
No. 3				

Total pumpage = 116,224.2 cu. feet.
Less slip 2 % = 2,324.2 cu. feet.
Total = 113,900.0 cu. feet.
Flow in cu. feet per second = 31.64
Average area of tunnel section = 51.35 sq. feet.
Mean velocity = V = 0.607 ft. per sec.

PUMPAGE

CENTRAL PARK AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches.	REMARKS
No. 1	1	1058	49.64	Net area of plungers 926.52 sq. in.
No. 2	—	—	—	
No. 3	—	—	—	

Total pumpage = 112,639.0 cu. feet.
Less slip 1½ % = 1,689.0 cu. feet.
Total = 110,950.0 cu. feet.
Flow in cu. feet per second = 30.82
Average area of tunnel section = 50.95 sq. feet.
Mean velocity = V = 0.605 ft. per sec.
Mean velocity = V = 0.736 ft. per sec. in contracted section.

CRIB TO GREEN STREET

Flow in cu. feet per second = 62.46
Average area of tunnel section = 79.12 sq. feet.
Mean velocity = V = 0.789 ft. per sec.

14.

GAUGINGS NO. 4

DATE, July 30, 1903

SHAFT	Average Gauge Readings	Corrections Nov. 23 Read'g	Corrections Aug. 30 Read'g	Corrected Readings	Head H	Corrected Head hs	OBSERVER
CRIB	+0.313		+0.120	+0.433			Martin Zatterberg. Shaft Gauge at Crib used.
KINGSBURY ST.	-2.752		+0.051	-2.701	3.134	2.956	E. P. Scott.
GREEN ST.	-2.971		+0.000	-2.971	0.270	—	W. W. Marr
KEITH ST	-3.519		+0.045	-3.474	0.503	—	L. C. Harnett.
SPRINGFIELD AV.	no readings		-0.022	—	—	—	—
CARROLL AV.	-3.239		-0.007	-3.246	0.275	—	Harry K. W eks.
CENTRAL PK. AV.	-5.057		+0.068	-4.989	1.743	—	R. A. J. Shaw.

$$H = h + h_1 + h_2 + h_3 + h_4 + h_5$$

h = velocity head = 0.078
h_1 = entry head at gates = 0.000 Inside Gauge used.
h_2 = entry head at tunnel = 0.050
h_3 = head due to enlargement = 0.050
h_4 = head due to contraction = negligible.
h_5 = friction head.

PUMPAGE

SPRINGFIELD AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke Inches	REMARKS
No. 1	3	3204	49.378	Net area of plungers
No. 2	3	3195	49.378	926.52 sq. in.
No. 3	3	3179	49.073	

Total pumpage = 1.012.250.0 cu. feet.
Less slip 3 % = 30.368.0 cu. feet.
Total = 981.882.0 cu. feet.

Flow in cu. feet per second = 90.91
Average area of tunnel section = 51.35 sq. feet.
Mean velocity = V = 1.772 ft. per sec.

PUMPAGE

CENTRAL PARK AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke Inches.	REMARKS
No. 1	3	3062	49.079	Net area of plungers
No. 2	3	3153	48.735	926.52 sq. in.
No. 3	3	2966	48.913	

Total pumpage = 963.010.0 cu. feet.
Less slip 3 % = 28.890.0 cu. feet.
Total = 934.120.0 cu feet.

Flow in cu. feet per second = 86.50
Average area of tunnel section = 50.95 sq. feet
Mean velocity = V = 1.698 ft. per sec.
Mean velocity = V = 2.095 ft. per sec. in contracted section.

CRIB TO GREEN STREET

Flow in cu. feet per second = 177.41
Average area of tunnel section = 79.12 sq. feet
Mean velocity = V = 2.243 ft. per sec.

15.

GAUGINGS No. 5

DATE, August 7, 1903.

SHAFT	Average Gauge Readings	Corrections Nov. 30 Read'g	Corrections Aug. 23 Read'g	Corrected Readings	Head H	Corrected Head hs	OBSERVER
CRIB	+0.339		+0.120	+0.459			Martin Zatterberg. Well Gauge at Crib used.
KINGSBURY ST.	-3.286		+0.051	-3.235	3.694	3.308	E. P. Scott.
GREEN ST.	-3.529		+0.000	-3.529	0.294		W. W. Marr.
KEITH ST	-4.110		+0.045	-4.065	0.536		L. C. Harnett.
SPRINGFIELD AV.	-6.568		-0.022	-6.590	2.525		Richard Bow.
CARROLL AV.	-3.827		-0.007	-3.834	0.305		Harry K. Weeks.
CENTRAL PK. AV.	-5.978		+0.068	-5.910	2.076		W. J. Griffen.

$H = h + h_1 + h_2 + h_3 + h_4 + h_5$

h = velocity head = 0.084
h_1 = entry head at gates = 0.202 observed.
h_2 = entry head at tunnel = 0.050
h_3 = head due to enlargement = 0.050
h_4 = head due to contraction = negligible.
h_5 = friction head.

PUMPAGE

SPRINGFIELD AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches	REMARKS
No. 1	3	3275	49.616	Net area of plungers 926.52 sq. in.
No. 2	3	3258	49.535	
No. 3	3	3081	49.431	

Total pumpage = 1.021 262.0 cu. feet.
Less slip 3 % = 30.638.0 cu. feet.
Total = 990.624.0 cu. feet
Flow in cu. feet per second = 91.73
Average area of tunnel section = 51.35 sq. feet.
Mean velocity = V = 1.788 ft. per sec.

PUMPAGE

CENTRAL PARK AVE. PUMPING STATION

ENGINE	No. Hours Run	Total Rev.	Ave. Stroke inches	REMARKS
No. 1	3	3238	49.285	Net area of plungers 926.52 sq. in.
No. 2	3	3323	49.205	
No. 3	3	3118	49.304	

Total pumpage = 1.022.653.0 cu. feet
Less slip 3. % = 30.680.0 cu. feet.
Total = 991.973.0 cu. feet.
Flow in cu. feet per second = 91.85
Average area of tunnel section = 50.95 sq. feet
Mean velocity = V = 1.803 ft. per sec.
Mean velocity = V = 2.225 ft. per sec. in contracted section

CRIB TO GREEN STREET

Flow in cu. feet per second = 183.58
Average area of tunnel section = 79.12 sq. feet.
Mean velocity = V = 2.320 ft. per sec

16.

RESULTS OF GAUGINGS

IN

NORTHWEST LAND AND LAKE TUNNELS

CHICAGO, ILL.

CROSS SECTIONS OF TUNNELS CIRCULAR, LINING--SEWER BRICK IN CEMENT MORTAR
AVERAGE AREAS OF CROSS SECTIONS OBTAINED BY NUMEROUS MEASUREMENTS.
BRICK HARD BUT SOMEWHAT IRREGULAR IN SHAPE WORKMANSHIP FAIR

SECTION: CRIB TO KINGSBURY ST.

LENGTH, 20,483 FEET.

BLASTING RESORTED TO IN GREATER PORTION OF THIS SECTION
SOIL: HARD CLAY AND HARD PAN. ABOUT 600 FEET OF QUICKSAND ON LAKE SECTION

NUMBER & DATE OF GAUGINGS.		AV. AREA OF CROSS SECT.	HYDRAULIC MEAN RADIUS	SLOPE OF WATER PER THOUSAND 1000 S.	MEAN VEL. FT PER SEC. V.	COEFFICIENT IN FORMULA $V = C\sqrt{RS}$ C.	COEFFICIENT OF ROUGHNESS n.	REMARKS.
1	October 15th, 1902	79.12	2.52	0.1001	1.933	121.7	0.0142	
2	October 31st, 1902	79.12	2.52	0.1095	1.996	120.2	0.0143	
3	November 6th, 1902	79.12	2.52	0.0204	0.789	110.02	0.0151	
4	July 30th, 1903	79.12	2.52	0.1443	2.243	117.6	0.0147	
5	August 7th, 1903	79.12	2.52	0.1615	2.320	115.0	0.0150	

Average value of coefficient of roughness, eliminating Gaugings №3; n = 0.01455

$$n = \sqrt{\frac{1.811\sqrt{R}}{BC} + \frac{1}{4}\left(\frac{C-B}{BC}\right)^2 R} - \frac{1}{2}\left(\frac{C-B}{BC}\right)\sqrt{R}; \qquad B = 41.6 + \frac{0.00281}{S}$$

SECTION: KINGSBURY ST. TO GREEN ST.

LENGTH, 2,216 FEET.

VERY LITTLE BLASTING IN THIS SECTION SOIL HARD BLUE CLAY

1	October 15th, 1902	79.12	2.52	0.0911	1.933	127.5	0.0135	
2	October 31st, 1902	79.12	2.52	0.0975	1.996	127.4	0.0135	
3	November 6th, 1902	79.12	2.52	0.0135	0.789	135.1	0.0123	
4	July 30th, 1903	79.12	2.52	0.1218	2.243	128.0	0.0133	
5	August 7th, 1903	79.12	2.52	0.1327	2.320	126.9	0.0136	

Average value of coefficient of roughness, eliminating Gaugings №3; n = 0.01347

SECTION: GREEN ST. TO KEITH ST.

LENGTH, 3,328 FEET.

BLASTING RESORTED TO ALL THROUGH SECTION. SOIL GREEN ST END HARD CLAY
KEITH ST END LIMESTONE

1	October 15th, 1902	51.35	2.02	0.0493	1.160	116.3	0.0139	
2	October 31st, 1902	51.35	2.02	0.0613	1.170	105.1	0.0154	
3	November 6th, 1902	51.35	2.02	0.0240	0.607	87.1	0.0178	
4	July 30th, 1903	51.35	2.02	0.1511	1.772	101.4	0.0162	
5	August 7th, 1903	51.35	2.02	0.1610	1.788	99.1	0.0166	

Average value of coefficient of roughness, eliminating Gaugings №3; n = 0.01552

17.

RESULTS OF GAUGINGS

—IN—

NORTHWEST LAND AND LAKE TUNNELS

CHICAGO, ILL.

CROSS SECTIONS OF TUNNELS CIRCULAR. LINING-SEWER BRICK IN CEMENT MORTAR
AVERAGE AREAS OF CROSS SECTIONS OBTAINED BY NUMEROUS MEASUREMENTS
BRICK HARD BUT SOMEWHAT IRREGULAR IN SHAPE WORKMANSHIP FAIR

SECTION: KEITH ST. TO SPRINGFIELD AVE.

LENGTH, 18,855 FEET.

BLASTING RESORTED TO IN THE ENTIRE SECTION SOIL. LIMESTONE ROCK

NUMBER & DATE OF GAUGINGS.		AV. AREA OF CROSS SECT.	HYDRAULIC MEAN RADIUS	SLOPE OF WATER PER THOUSAND 1000 S.	MEAN VEL. FT. PER SEC V.	COEFFICIENT IN FORMULA $V = C\sqrt{RS}$ C.	COEFFICIENT OF ROUGHNESS n.	REMARKS
1	October 15th, 1902	51.35	2.02	0.0529	1.160	112.2	0.0144	
2	October 31st, 1902	51.35	2 02	0.0600	1.170	106.3	0.0152	
3	November 6th, 1902	51.35	2 02	0.0203	0.607	94,8	0.0163	
4	July 30th, 1903	51.35	2.02	——	——	——	——	NO GAUGE READINGS TAKEN
5	August 7th, 1903	51.35	2.02	0.1338	1.788	108.7	0.0152	

Average value of coefficient of roughness, eliminating Gaugings N°3; n = 0.01493

SECTION: GREEN ST. TO CARROLL AVE.

LENGTH, 2,759 FEET.

BLASTING PARTLY RESORTED TO IN THIS SECTION SOIL HARD CLAY.

1	October 15th, 1902	50.95	2.015	0.1196	1.830	118.1	0.0140	
2	October 31st, 1902	50.95	2.015	0 1261	1.923	120.6	0.0138	
3	November 6th, 1902	50.95	2.015	0.0214	0.605	92.2	0.0167	
4	July 30th, 1903	50.95	2.015	0.0997	1.698	119.8	0.0138	
5	August 7th, 1903	50.95	2.015	0.1105	1.803	120.8	0.0137	

Average value of coefficient of roughness, eliminating Gaugings N°3; n = 0.01382

SECTION: CARROLL AVE. TO CENTRAL PARK AVE.

LENGTH OF NORMAL SECTION, 16,247 FEET.
LENGTH OF CONTRACTED SECTION 850 EEET

BLASTING RESORTED TO IN THIS SECTION, BRICK WORK NOT DISTURBED.
SOIL CARROLL TO HOYNE AVES, BLUE CLAY HOYNE TO CENTRAL PARK AVES, LIMESTONE ROCK

1	October 15th, 1902	50.95 41.28	2.015 1.825	$\frac{hs}{Ls} \times 1000$ 0.1188	1.830 2.140	118.4	0.0140	
2	October 31st, 1902	50.95 41.28	2.015 1.825	0.1259	1.923 2.341	120.7	0.0137	
3	November 6th, 1902	50.95 41.28	2.015 1.825	0.0136	0.605 0.736	108.5	0.0138	
4	July 30th, 1903	50.95 41.28	2.015 1.825	0.0986	1.698 2.095	120.5	0.0137	
5	August 7th, 1903	50.95 41.28	2.015 1.825	0.1174	1.803 2.225	117.2	0.0140	

Average value of coefficient of roughness, eliminating Gaugings N°3; n = 0.01385

The greater portion of the Lake section of this tunnel was lined with sewer brick laid in Portland cement mortar, and the balance of the Lake section and the Land portion with sewer brick laid in Utica cement mortar. The bricks were fairly uniform in size and make. The workmanship was good, and while the mortar joints were not scraped or pointed, there was no unusual roughness of the inside surface of the tunnel apparent to the eye. Blasting was resorted to in the greater portion of this tunnel, and this may have loosened the mortar joints and increased the roughness to some extent. Otherwise it was a sample of good brick sewer or tunnel work.

The aggregate of the smaller losses of head have been deducted from the total head H for this section only, the small losses for any other section having been neglected and indirectly included in the coefficients. These small losses have for section Crib-Kingsbury been determined by formulæ in general use as follows:

$$\text{Velocity head } h = \frac{v^2}{2g}$$

Loss of head through gate openings in shaft

$$h_1 = \frac{v_1^2}{c^2.2g}$$

These losses were obtained by a series of experiments with the velocity v_1 of the water through the gate openings varying from 1.6 to 2.2 ft. per second. By these experiments the coefficient c in formula $v = c\sqrt{2gh}$ was ascertained and applied in each case.

The loss h_2 on account of the square bend at the bottom of the shaft, was calculated by the formula

$$h_2 = \frac{\alpha}{180}\,\frac{n_1 v_2^2}{2g}$$

where n_1 varies according to the ratio $\frac{r}{r_1}$, n_1 being 0.13 for $\frac{r}{r_1} =$ 0.1 and reaching a value of 0.98 when $\frac{r}{r_1}$ is 0.8 and 1.98 when $\frac{r}{r_1} = 1$, making allowance for the fact that the shaft has a diameter 2 ft. larger than the tunnel.

In the above α represents the angle of the bend.

v_2 represents the velocity of the water in the tunnel.

r represents the radius of the tunnel.

r_1 represents the assumed radius of curvature of the bend.

The loss of head h_3 on account of enlargements of the tunnel, where the intermediate Lake shaft and the Oak Street shore shaft intersected the tunnel, was calculated by the formula

$$h_3 = \left(\frac{a_2}{a_1} - 1\right)^2 \cdot \frac{v_2^2}{2g}$$

in which a_2 equals area of, and v_2 the velocity of, the water through the cross-section of the enlargement, and a_1 equals area of the cross-section of the regular tunnel. The area of the enlargements in this case is not of the same form as the tunnel proper, and has been taken as 176 square feet in each case. The losses of head on account of the water passing from a larger to a smaller section at these same places are so small that they have been neglected.

While the determination of some of these losses of head may not be even approximately correct, the aggregate of all of them is comparatively small and does not greatly affect the results.

The average of the calculated value of the coefficient of roughness n for this section (omitting the gaugings of November 6, 1902, where the small slopes will make the slightest error in gauge readings affect the results appreciably) is 0.01455. This is rather a larger value than the author would expect, considering the character of the brickwork as he remembers it and as compared with other sections of the tunnel, as there was no disturbance on account of the blasting perceptible to the eye on a general inspection of the brickwork in this section.

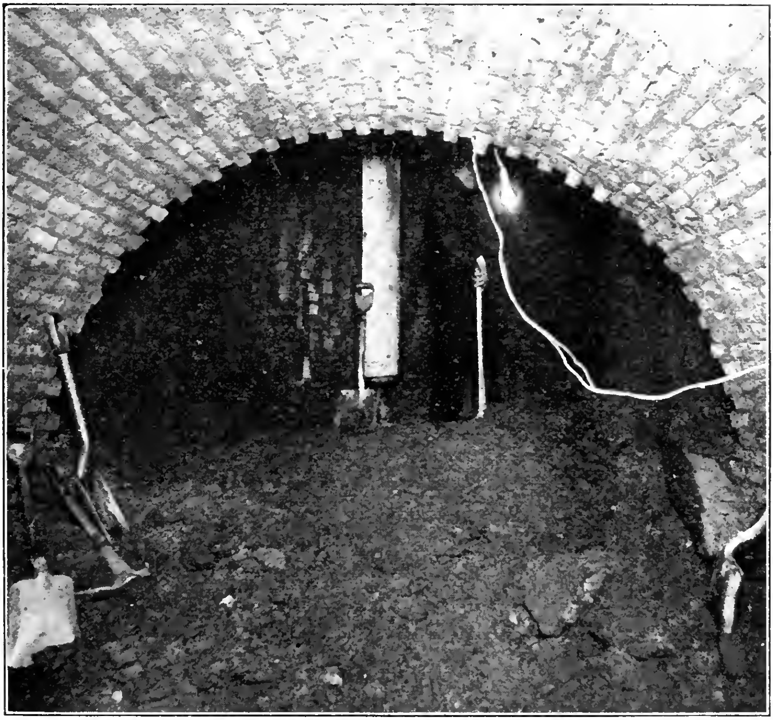
There is a connecting tunnel between this system and the Chicago Avenue tunnel system. On this connecting tunnel, which has an inside diameter of 7 ft., there is a gate shaft and a 7 ft. gate, which was closed during the time of these gaugings. If there was any leak whatever through or around this gate, it could have been but very small. The greater resistances in this section may be ascribed to the effect on the brick work by blasting, even though this was not especially noticeable, as before stated, no close inspection having been made at that time with this purpose in view.

There is a possibility that the losses of head on account of enlargements, etc., are greater than calculated, in which case n as determined would be a trifle too large, but this cannot anywhere near make up for the difference in the value of n.

The photograph of the interior of this section is fairly representative of the entire section.

Section Kingsbury-Green. This section is a continuation of the former section. It consists of a 10 ft. tunnel and is 2216 feet long.

The workmanship on this section was especially good, the ground through which the tunnel was excavated being very favorable for tunneling, and somewhat less blasting was done in this section owing to previous frequent complaints of property owners, their buildings having been more or less shaken. This difference as compared with the Section Crib-Kingsbury, as far as appearances were concerned, would, however, hardly account for the difference in the value of n. This stretch of tunnel being rather short and the slope correspondingly small, slight errors in the readings would affect the results more than for longer stretches of tunnel. The floating gauges may have given less accurate results, but gaugings Nos. 4 and 5 should be very reliable. If the small losses of head due to eddies in the shafts were deducted from the total head, a still smaller value of n would be obtained.

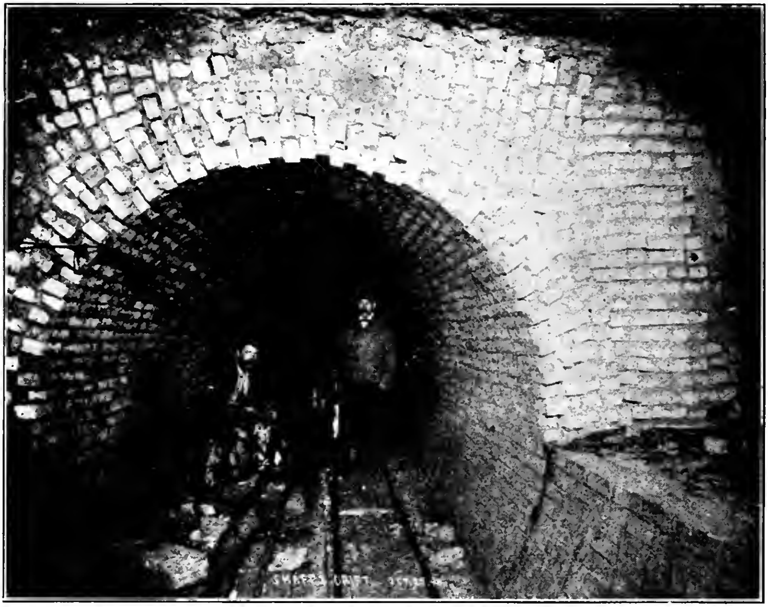


View Inside the Conduit Showing the Brick Work.

Section—Kingsbury-Green.

The column of water, when reaching the Green Street shaft, divides, part of it continuing in practically a straight line through the 8 ft. tunnel to the Central Park Avenue pumping station, and part of the flow following the shaft upwards for a distance of about 11 ft. to the entrance of the 8 ft. tunnel leading to the Springfield Avenue station, then turning an abrupt angle of 90° and along the tunnel to the pumping station. To what extent these conditions affect the slope for this and the adjoining sections, the author does not attempt to state.

Section Green-Keith. This section of the tunnel 3328 ft. long was constructed partly through hard pan and clay and partly through limestone rock. The workmanship and smoothness of the interior surface was originally good, but the brickwork along this entire branch of the system was more or less shaken up and in places distorted by the constant blasting in the tunnel, and it was not possible to entirely remedy this. This fact, as well as several irregularities in grade and alignment, will account for the rather large *n* for this, and the following section.



View Inside a Completed Portion of Conduit—Showing the Brickwork.

Section—Keith-Springfield.

Section Keith-Springfield Ave. Whatever has been said in regard to the Section Green-Keith applies also to this section, which is 18,855 ft. long. There is some additional loss of head at the entrance to the tunnel in the gate shaft at Keith Street, as well as at the 90° square bend at the junction between the tunnel and shaft at the pumping station, but these losses are also the same for the Central Park branch. These losses have not been considered, but would decrease the value of n to some very slight extent if eliminated.

Section Green-Carroll. The branch of the tunnel system of which this section forms a part was constructed partly through clay and hard pan (from Green Street to Hoyne Avenue) and partly through limestone rock (Hoyne Avenue to Central Park Avenue). Blasting was resorted to in both the earth and the rock part of the tunnel, but in the rock section nearly all the excavating was done before the brickwork was laid. There was much less, if any, disturbance at all of the brickwork through blasting in this than in the northwest branch leading to Springfield Avenue, at least in Section Carroll-Central Park, the earth section in that part of the tunnel being mostly plastic clay. From Green Street to Carroll Avenue the soil was rather hard boulder clay, and a little more blasting was done here than in the earth part of Section Carroll-Central Park.

Although the brickwork appeared in some stretches to be laid with less skill in this entire branch, and in places presented ridges at the springing line where the invert and arch join, a rougher invert through the clay section, and generally a somewhat less smooth interior surface than any of the other sections, the coefficient of roughness n is smaller than for the Springfield Avenue branch.

This section has a length of 2759 ft.

Section Carroll-Central Park. As stated above, that portion of this section extending from Hoyne Avenue to Central Park Avenue was constructed through limestone rock, the remaining part from Carroll Avenue to Hoyne Avenue being constructed through clay. Most of the brickwork was laid after all of the excavation had been completed in the rock section. From Hoyne Avenue east for a distance of 850 ft., an extra ring of brickwork was ordered placed in this tunnel, thus reducing the diameter through this part of the tunnel from 8 ft. to 7 ft. 3 in. The total length of this section is 17,097 ft., of which 850 ft. has a diameter of 7 ft. 3 in. and 16,247 ft. a diameter of 8 ft.

In calculating the values of C and n for this section, the value of C has been assumed to be the same for the contracted section as for the full 8 ft. section. This assumption, on account of the comparatively small length of the contracted section, even if not correct, cannot affect the results appreciably. The value of C for this section was calculated in the following manner:

Let V_7=mean velocity of flow through contracted section.

Let V_8=velocity of flow through 8 ft. section.

Let L_7=length of contracted section=850 ft.

Let L_8=length of 8 ft. section=16,247 ft.

Let R_7=hydraulic mean radius for contracted section=1.825 ft.

Let R_8=hydraulic mean radius for 8 ft. section=2.015 ft.

Let h_7=head lost through contracted section.

Let h_8=head lost through 8 ft. section.

Let h_7+h_8=observed loss of head Carroll to Central Park Avenue.

$$\text{Then } V_7 = C\sqrt{R_7 \frac{h_7}{L_7}}\ ;\quad h_7 = \frac{V_7^2\, L_7}{C^2\, R_7}$$

$$V_8 = C\sqrt{R_8 \frac{h_8}{L_8}}\ ;\quad h_8 = \frac{V_8^2\, L_8}{C^2\, R_8}$$

$$h_7 + h_8 = \frac{I}{C^2}\left[\frac{V_7^2\, L_7}{R_7} + \frac{V_8^2\, L_8}{R_8}\right] \therefore C = \sqrt{\frac{\dfrac{V_7^2\, L_7}{R_7} + \dfrac{V_8^2\, L_8}{R_8}}{h_7 + h_8}}$$

$$\text{or } C = \sqrt{\frac{V_7^2\, L_7\, R_8 + V_8^2\, L_8\, R_7}{R_7\, R_8\, (h_7 + h_8)}}$$

The lower value of n obtained for the last two sections, Green to Carroll and Carroll to Central Park, especially the latter, the author is inclined to ascribe to the fact that there was no disturbance at all of the brickwork after being laid in the greater portion of this branch through blasting in this tunnel, and not much where the brickwork was laid intermittently with excavation work. From Green Street to Carroll Avenue there was more blasting than in the other part of the earth section, but not sufficient to seriously disturb the brickwork. The results in general also seem to indicate that blasting in a tunnel with a brick lining in such a manner that the lining is at all disturbed, whether such disturbance is especially noticeable or not, will have the effect of increasing the resistances to flow and consequently decrease the capacity of such a tunnel. The jarring of the brickwork undoubtedly disturbs the mortar joints more or less, so that the bond with the brick will be broken. Slight projections and irregularities will be caused by this shaking of the brickwork, and irrespective of any visible disturbance or distortion of the same, resistances to the flow of water seem to have been created.

A brick tunnel in rock should not be lined until after the completion of the entire excavation, or at least the brick lining should be kept far enough back of the face and be so protected as to be unaffected by the blasting.

In an earth tunnel, blasting should preferably not be permitted at all, and if anywhere found to be necessary care should be taken to protect the brickwork from the effect of such blasting and to remedy any defects in the brickwork that upon close inspection may be discovered.

CONCLUSION.

The author, from his experience with these as well as other similar cases, is of the opinion that for tunnels or sewers of ordinary sizes and velocities of flow, lined with sewer brick laid in cement mortar, if the brick is properly selected and not too warped or uneven, laid in a workmanlike manner and true to line, not disturbed by blasting, and the mortar joints scraped off flush with the brick, a coefficient of roughness n in Kutter's formula of 0.0130 is readily attainable, if the extraordinary resistances to flow, such as bends, enlargements, etc., are eliminated.

Under certain circumstances, especially if there has been any disturbance whatever of the brickwork on account of blasting, it will be found advisable and profitable to have in addition the entire interior surface of brick conduits washed with neat cement, the strokes of the brush applying the wash to be always longitudinally parallel with the axes of the conduit. By this method a coefficient of roughness, n, considerably smaller than 0.0130 should be obtained in well constructed tunnels of the sewer brick lined class.

Discussion

L. K. Sherman, M. W. S. E. (Chairman): It is unnecessary to point out to this audience the very great value of these investigations. It is fortunate for the engineering profession that men active in executive life are ready to devote valuable time to research work of this nature. The engineering colleges, and professors connected therewith, have done valuable work. They have done the bulk of this research work which is the foundation for all scientific and practical engineering, but there are certain phases and conditions that the professors and the universities cannot reach. This paper is one that could not very well be reached by the professors.

*C. F. Schulz** (by letter:) Test of flow and corresponding loss of head in the East Side Tunnel of the Cleveland Water Works, as calculated from observation made October 27, 1909, but corrected for slippage of pumps as determined April 10 and 11, 1911.

This test was made at the request of Messrs. John Ericson and Howard Carson to determine approximately the probable loss of head under varying conditions of flow.

The East Side supply system of Cleveland consists of the

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*Chief Engineer, Water Dept., Cleveland, Ohio.

so-called East Side intake crib, or crib No. 3, located in Lake Erie, about four miles from shore, and a tunnel about five miles long extending from the intake shaft at this crib to shaft No. 5 at the Kirtland Pumping Station, from which shaft an aqueduct leads to the various pump wells.

This station is located on the shore of Lake Erie on East Forty-ninth Street. The pumping equipment at present consists of two Holly vertical, triple-expansion crank and flywheel pumping engines of 25,000,000 gallons capacity; two Knowles horizontal, duplex-compound, low-duty engines of 15,000,000 gallons each, and one Worthington horizontal, duplex-compound engine with high-duty attachment of 15,000,000 gallons capacity. Total pumping capacity, 95,000,000 gallons in 24 hours.

The estimated ultimate capacity of the tunnel is 175,000,000 gallons. The tunnel was completed in 1903, and since April, 1904, it has supplied all the water furnished by the City Water Department. The location of crib, tunnel, shafts and connection to aqueduct is shown herewith in Sheet A.

The nominal diameter of the tunnel is 9 ft., and the nominal area 63.62 sq. ft.

The average area based on the measurements of 1,221 vertical and 1,221 horizontal diameters is 64.5337 sq. ft.

The average diameter equals 9.064 ft.

The hydraulic mean radius equals 2.266 ft.

The intake shaft is 10 ft. in diameter and 82.4 ft. deep from top of shaft, about 25 ft. below lake level, to the center of the tunnel. Shaft No. 5 is 10 ft. in diameter at the top and 10.5 ft. in diameter at the tunnel, and is 76.2 ft. deep from the center of the aqueduct to the center of the tunnel. The length of the tunnel from the intake shaft to shaft No. 5 is 25,834 ft. The total length of the intake and outlet shaft and tunnel is 26,043 ft.

The tunnel was built of shale brick laid in natural cement mortar. The mortar projecting on the inner surface was roughly scraped after the centers were struck, but no particular pains were taken to make the work any smoother than ordinary sewer brickwork.

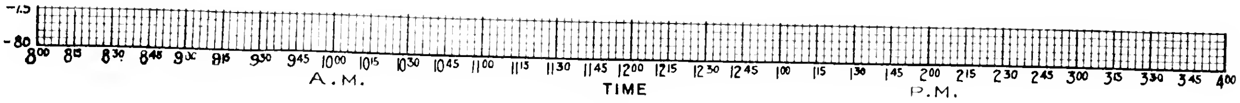
The total length of the tunnel and shaft is shown on Sheet A.

The diagram *B* shows the rate of flow in the tunnel, expressed in gallons per 24 hours, with the mean velocity of flow in feet per second, and the corresponding loss of head in tunnel and shafts.

The elevations of the water in the pump well No. 2 simply show the loss of head from shaft No. 5 to the pump wells through the gate shaft, screen well, aqueduct, and pump well branches.

The following are results obtained October 27, 1909, corrected for slippage of pumps as per tests made April 10 and 11, 1911:

Total average loss of head when rate of flow is 65,000,000 gallons in 24 hours, 2.2646 ft.


-75
-80
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8 45
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1 45
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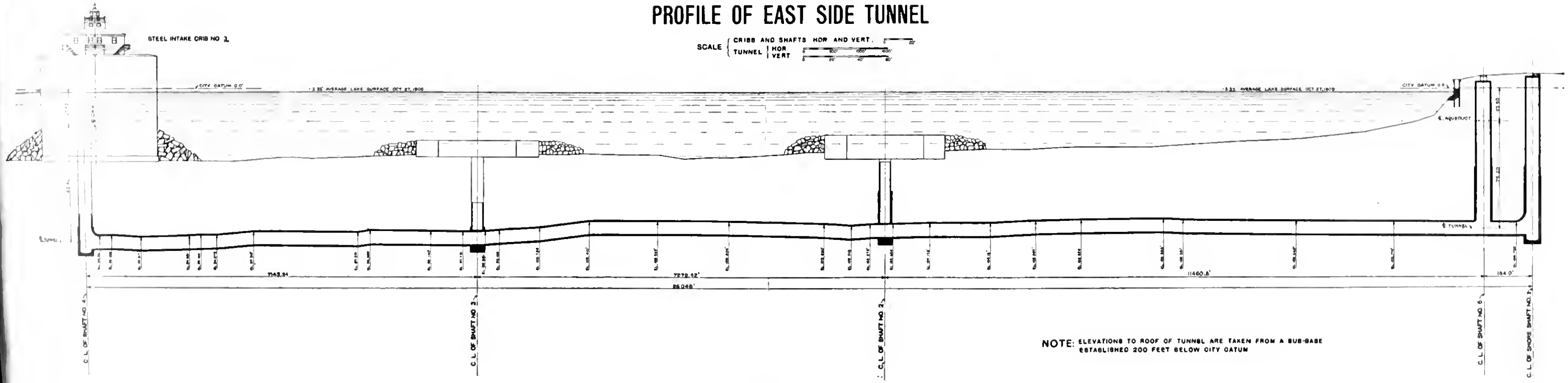
A.M.
TIME
P.M.

Diagram B.

City of Cleveland--Water Department.

PROFILE OF EAST SIDE TUNNEL



NOTE: ELEVATIONS TO ROOF OF TUNNEL ARE TAKEN FROM A SUB-BASE ESTABLISHED 200 FEET BELOW CITY DATUM

Sheet A.

City of Cleveland--Water Department

GAUGING OF EAST SIDE TUNNEL

SHOWING AVERAGE WATER LEVEL READING AND RATE OF FLOW IN TUNNEL.

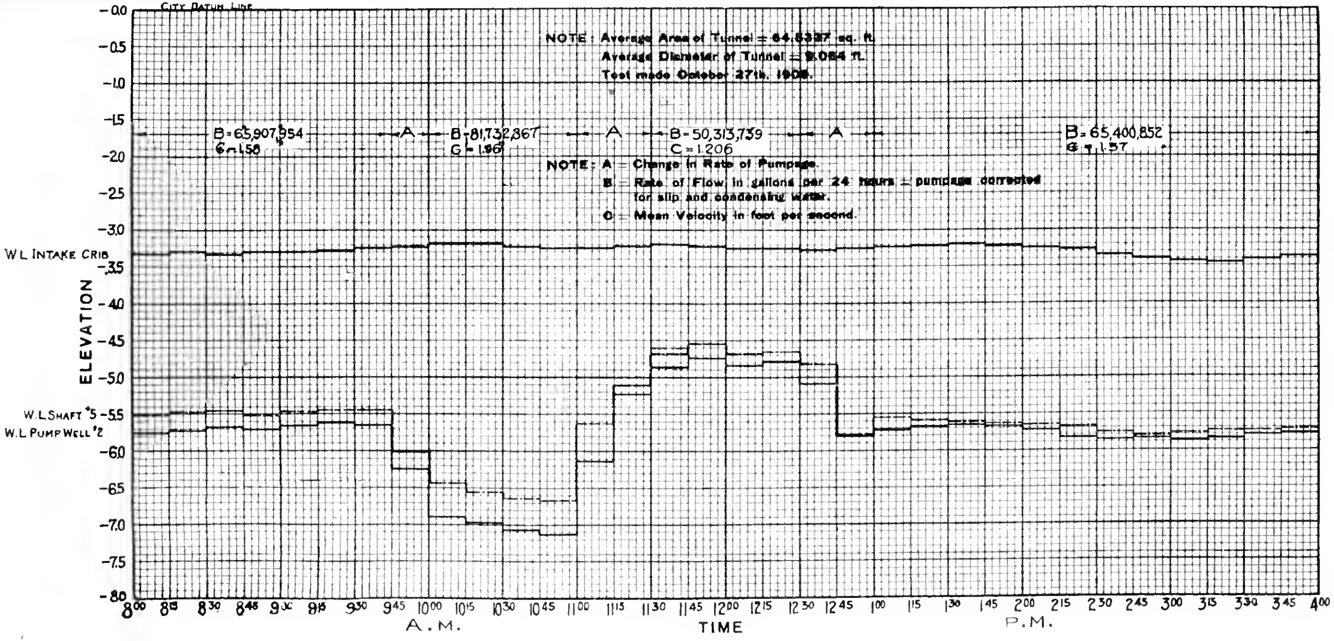


Diagram B.

Average area of tunnel, 64.5337 sq. ft.
Average diameter, 9.064 ft.
R (mean hydraulic radius), 2.266 ft.
Slope S, 0.000086949 ft.

The resultant coefficient of roughness, *n*, of Kutter's formula equals 0.0151.

S. G. Artingstall, M. W. S. E. (by letter): The investigations of the flow of water in bricklined conduits, as described in the paper before us, is a valuable contribution on this subject; for while experiments with pipes of small diameter are many, and often conflicting, experiments on conduits of large size are very few, and a faithful record of such observations are of great value to all who have occasion to deal in such constructions.

It is of the utmost importance that a clear and minute description of all resistances that may affect the head or velocity, be given, not only the degree of roughness and inequalities of the confining walls, and the changes of direction of line or grade, but also a detailed description of all accessories to the conduit, such as gates, bends, angles, shafts, sumps, and all enlargements and contractions, whether sudden or gradual, for all these are obstructions to a steady flow of the water and create eddies and cross currents; where there are a number of such obstructions, the accumulation of losses is a serious matter, and generally no remedy for such defects can be applied after the conduit is in use.

That such obstructions do cause a large portion of loss of head is clearly shown by the paper under discussion, but unfortunately it is impossible to determine the loss due to each obstruction. The aggregate loss, or the sum of the whole, may be at least approximately arrived at.

In discussing the paper it may not be amiss to call the attention of the members of this Society to a paper on the flow of water in conduits 12 ft., 7 ft., and 5 ft. diameter, respectively, read before this Society at a meeting held April 6, 1880, and published in the proceedings of that date, in which paper is tabulated the readings and the results of the observations. A comparison of the two papers shows very clearly the great losses arising from obstructions, such as shafts, etc., as well as the loss of head due to friction of the side walls.

It will not be out of place at this time to give a very brief abstract from that paper descriptive of the tunnels under observation, and the mode of conducting the experiment. For a fuller account, I refer you to the paper itself.

In the conduit 12 ft. diameter, the observations were made by an electric current meter, which was tested at different velocities, both before and after the observations were made.

Readings were made with the meter held at different positions in the conduit at the following distances above the bottom, viz.:

8 in., 1 ft. 8 in., 1 ft. 11 in., 2 ft. 10 in., and at center; the length under observation was 8,900 ft., and the obstructions to flow 16 shafts 6 ft. diameter, 2 shafts 12 ft. diameter, and two bends 45 ft. radius, under a vertical angle of 30°.

In the 5 ft. tunnel the observations of the velocities were also taken by electric current meter held at center and at many positions from the sides and bottom; in all, 396 observations were taken, occupying a period of three days. The quantity of discharge is given by pump measurement, and the head both in this and the 12 ft. tunnel was measured by hook gauges reading to 0.001 ft. placed in still-water boxes.

The length of the tunnel under consideration was 10,500 ft. and at the time was believed to be free from all obstructions, but some years later the tunnel was pumped dry, and the writer with others, was much surprised to find that to facilitate the work during construction no less than twelve chambers for the storage of material had been constructed and allowed to remain open. These chambers were of the same diameter as the tunnel, about equal distances apart, and were partly filled with very fine silt, in which were large quantities of fresh-water clams in free and healthy condition. The silt in all the chambers assumed the shape as in Sketch No. 1, and showed the marks and results of eddies. The silt was firmly compacted, except on the surface where it was looser, having been doubtless disturbed somewhat by drawing off the water from the tunnel. It is needless to say that these chambers were closed before water was again admitted into the tunnel.

In the same paper there is also a table giving the results of observations on the same tunnel by a party of hydraulic engineers, the discharge measured by weir and by tunnel formula which is for a tunnel 5.1 ft. diam. $V = 136 \sqrt{I}$, and for a tunnel 7.1 ft. diam. $V = 164 \sqrt{I}$. Mr. Davis at Boston used the formula:

$$V = 127\, R^{0.62}\, I^{0.50}$$

In these formulae I is the sine of the slope, R the hydraulic radius, and V the mean velocity.

The record of observations on the tunnel 7.1 ft. diam. is also tabulated in the same paper. The experiments were made on a section 20,500 ft. between stations, with obstructions to the flow of 9 shafts 8 ft. diam., and 8 shafts 6 ft. diam. The tunnel is a straight line between the stations without bends or angles. The observations were taken in the shafts, the distance between them being about two-thirds the total length of the tunnel.

The experiments were made after all possible or probable causes of error were eliminated. The quantity of water flowing through the tunnel was determined by weir measurement. This weir was located on the grounds of the Ashland Avenue Pumping Station, was over 40 ft. long, with knife edge 11 ft. long, and full end contractions. Suitable means were taken to eliminate all eddies by lattice work where the water entered, and head due to velocity of approach was noted. The readings both on weir and in tunnel were taken by hook gauges, reading to 0.001 ft. placed in still-water boxes. Readings were taken every five minutes for a period of five days; in all, 456 observations are recorded with velocities varying from 0.4606 ft. to 1.2129 ft. per second, with heads on a length of 20,500 ft. from 0.226 ft. to 1.734 ft.

To insure the zero of the gauges being on the same level before any observations were made, all gates and connections to the tunnel were closed and means taken to be assured that no leakage occurred; and after the water was in a quiescent state, the gauges in both shafts were read every five minutes for a period of six consecutive hours, after which the gauges were permanently fixed at the zero thus obtained.

I may remark that during the six hours in which readings were taken the same phenomena observed by Mr. Ericson and shown on Plate VI, were met; viz.: a periodic and simultaneous rise and fall in both shafts 20,500 ft. apart.

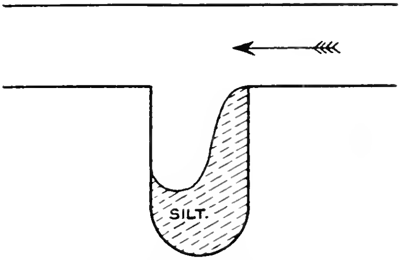
From a study of these experiments, it was very evident in all cases that the head on the conduits was far greater than that required to overcome the adhesion of the water to the walls of the tunnel and the friction of the molecules of the water against the surface of the walls.

In all cases the walls are built of common brick possessing all the characteristics of well-built masonry, and all of about the same degree of roughness and uniform in character, throughout their length. Now the sum of the reactions of the flowing water against the innumerable projection causing small eddies (or friction) in a uniform channel is directly as the length and proportional to the head to which the velocity is due which is proportional to the square of the velocity. The resistance arising from the interior of a straight channel of uniform section and character of surface throughout is therefore not only as the length but as the square of the velocity.

The effect of the resistance is not equal in all the particles in a section of water channel, but is greatest at the exterior and least at the center, or in a given section approximately as its circumference divided by a function of its area. This variation is well shown by the tables where the velocities are taken by current meter under practically the same head as in Table No. 1 on the 5 ft. tunnels in the first series of observations. The velocity at the center is 1.7875 ft. per sec. The velocity at 4½ in. from the side is 1.4527 ft. per sec.

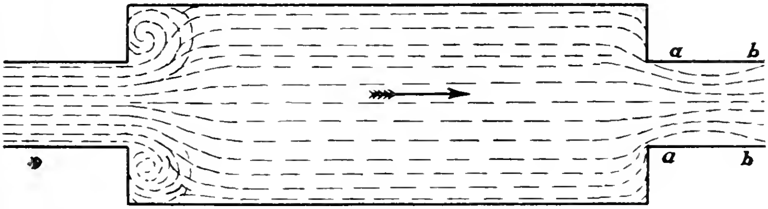
In the second series the velocity at the center is 1.8495 ft. per sec.; the velocity at 4 in. from side is 1.7113 ft. per sec.

In the third series the velocity at 15 in. from bottom is 1.8446



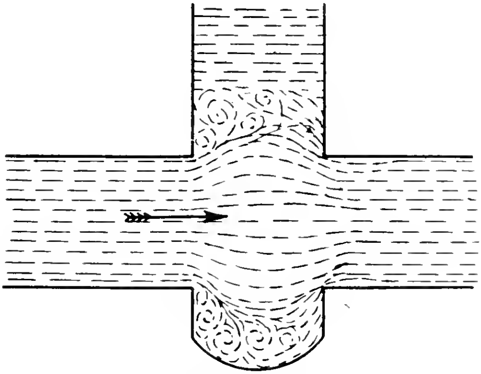
SKETCH I.

SHOWING ACCUMULATION OF SILT IN CHAMBERS OF 5 FT. TUNNEL.



SKETCH 2.

SHOWING SUDDEN CONTRACTION AND EXPANSION WITH A STEADY FLOW BETWEEN.



SKETCH 3.

SHOWING VIOLENT OBSTRUCTION AT A TYPICAL SHAFT.

ft. per sec., and the velocity at 5 in. from bottom is 1.7337 ft. per sec.

In the fourth series the velocity at center is 1.8918 ft. per sec., and the velocity at 4 in. from side is 1.5507 ft. per sec.

In all cases the head remains practically the same, and the intermediate positions of the meter show increase of velocity from the sides or bottom toward the center.

For the conduit 12 ft. diameter the following abstract from Table No. 5 gives the velocity in feet per second for different positions of the meter:

Head on Conduit for a length of 8,900 ft.	Velocities in Feet Per Second. Location of Meter Above Bottom of Conduit. 8 in.	1 ft. 8 in.	1 ft. 11 in.	2 ft. 10 in.	Center
0.82	1.2836	1.423	1.386	1.445	1.6306
0.98714	......	1.723	1.7322	1.7851	1.6623
1.321	1.7	2.0512	2.1468	2.2454	2.1813
1.525	2.0569	2.0849	2.135	2.191	2.3
1.6947	1.9247	2.128	2.2316	2.304	2.355
1.9617	1.1755	2.4678	2.4808	2.5186	2.4681

Now when the flow of water in conduits, in addition to the resistances offered by the degree of roughness of the walls, is suddenly enlarged or contracted by shafts, gates, or other accessories, large disturbing eddies are suddenly created, which cause great obstruction to the steady flow, and this will retard the flow through the whole section (for while the comparatively small inequalities, although great in the aggregate, have litte retarding influence on the center filaments, particularly if the section of water is large and the flow steady and uniform), in the case of shafts where a sudden enlargement is immediately followed by a contraction to the original size; the uniform steady flow is arrested and results in violent eddies affecting the whole section. These eddies are projected against the immovable wall on the opposite side of the shaft, causing much commotion at this point with a proportional loss of head. This loss is more in a shaft and is a greater loss than would be the case of a sudden enlargement followed by a conduit of the enlarged size and of sufficient length to allow the water to assume a uniform and steady flow before the construction to the original size is made. Take a case as shown by Sketch 2; when a stream changes section abruptly, rotating eddies are formed which dissipate energy, and the head absorbed in producing eddies is at once abstracted from that effective in causing the flow, and sooner or later is wasted by friction resistance due to the rapid relative motion of the eddying part of the water; the work thus expended internally in the water is too important to be neglected. The velocity and steady flow of the water is suddenly obstructed and delayed by a stream of less velocity in the enlarged section, and this shock affects the flow for some distance prior to entering the enlarged portion of the conduit, and work is expended in producing irregular eddying motion, both by shock and by sudden change in the section of the conduit. Let V and V_1 be the relative velocities of the two parts of the stream. Then when an abrupt change of section occurs, the head due to the relative velocity is lost in shock or $\frac{(V - V_1)^2}{2g}$ is wasted. Now this equation only accounts for the loss due to the change of velocity or change of section or area for $\frac{V_1}{V} = \frac{a}{a_1}$ or if circular $\frac{V_1}{V} = \frac{d^2}{d_1^2}$, d and d_1 being the diameters.

Hence the head lost is $h_e = \frac{(V - V_1)^2}{2g} = \left(\frac{a_1}{a} - 1\right)^2 \frac{V_1^2}{2g} =$

$$\left(\frac{d_1^2}{d^2} - 1\right)^2 \frac{V_1^2}{2g} \text{ or } h_e = C_e \frac{V_1^2}{2g}$$

The following table gives the value of C_e:

$\frac{a_1}{a}$	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.5	3.0	3.5	4	5	6	7	8
$\frac{d_1}{d}$	1.05	1.1	1.14	1.18	1.22	1.26	1.3	1.34	1.38	1.41	1.58	1.73	1.87	2.0	2.24	2.45	2.65	2.83
C_e	0.01	0.04	0.09	0.16	0.25	0.36	0.49	0.64	0.81	1.0	2.25	4.0	6.25	9.0	16.0	25.0	36.0	49.0

When the water passes from a larger to a smaller section, a contraction is formed as in Sketch 2, and the contracted stream suddenly expands to fill the section of the pipe. Let a be the section and V the velocity of the stream at b-b; at a-a the section will be $C_c\,a$ and the velocity $\frac{a}{C_c a} v = \frac{v}{C_c}$, where C_c is the coefficient of contraction. Then the head lost is $h_c = \frac{\left(\frac{V}{C_c} - V\right)^2}{2g} = \left(\frac{1}{C_c} - 1\right)^2 \frac{V^2}{2g}$; and if C_c is taken at 0.64 then $h_c = 0.316 \frac{V^2}{2g}$. The value of the coefficient may be somewhat modified by friction.

I have taken the trouble to explain the losses due to sudden enlargement in a conduit where there is a sufficient length of the enlarged section to gain a steady and uniform flow before the sudden contraction takes place, so as to afford a comparison of this with a tunnel shaft as in Sketch 3, which is typical of such connections.

Now the head lost by a sudden enlargement is $\frac{(V - V_1)^2}{2g}$ and by a sudden contraction $0.316 \frac{V^2}{2g}$. The sum of these two comprise the loss from this cause, but these formulae cannot be applied in the case of a tunnel shaft, for while it is true that there is a sudden enlargement followed by a sudden contraction of the stream, the changes are so close together or such a short distance apart that the eddies formed are projected against the opposite walls of the shaft and against each other, causing a violent commotion at this point, and the loss of energy or head was very great in the 12 ft. conduit; the mean loss with shafts 6 ft. diameter at each shaft was $0.99 \frac{V^2}{2g}$ and in the 7 ft. conduit with shafts 8 ft. and 6 ft. diameter the mean loss was $2.04 \frac{V^2}{2g}$. From this it would seem that if the diameter of the shaft is small compared with the diameter of the tunnel, the loss is reduced.

The conclusion is evident that all such shafts and obstruction should be closed wherever possible after they have served their purpose in the construction of the work, and the conduit left with a straight or uniform surface and character from end to end.

Referring to the right angle bend at the foot of the shaft with "The loss h_2," under ANALYSIS OF RESULTS of the paper under discussion, the loss is taken by formula $h_2 = \frac{a}{180} \frac{N_1 V_2^2}{2g}$. Weisbach's formula for the loss of head for angles is $h_a = \left(0.9457 \; Sin.^2 \frac{\phi}{2} + 2.047 \; Sin.^4 \frac{\phi}{2}\right) \frac{V^2}{2g}$ which for an angle of 90° $= 0.984 \frac{V^2}{2g}$ or nearly unity.

The paper by Mr. Ericson I consider of much value to all engineers engaged in the design and construction of masonry conduits and interested in the study of hydraulics.

Rudolph Hering, M. W. S. E. (by letter): The experiments made and reported by Mr. John Ericson are timely and valuable for several reasons. They fill a needed want to establish the actual amount of friction in long and large conduits lined with brick masonry, a mode of construction, under conditions and on a scale which are rarely made available for experiment. They confirm the usefulness of a factor which expresses chiefly the degree of roughness of the wetted perimeter, which is of great importance when interpreting the discharges of water through conduits. They confirm what has often been contradicted, namely, that a slope formula, if carefully applied, may be safely used for conduits and pipes flowing full under pressure.

The experiments were made with evident care and are sufficiently extensive to give reliable results. Mr. Ericson has, therefore, earned an obligation from the profession for presenting a paper on an investigation of a financially important subject, and one that met and overcame a number of difficulties that are frequently encountered.

The work was novel in several respects. All features which might modify the main endeavor to establish the value of the coefficient of roughness for brickwork in a long conduit, were eliminated as far as practicable. The illustration shows presumably the average character of the brickwork, the form of the bricks, and the way the joints were made. Judging from the appearance the coefficient resulting from the experiments, in the writer's opinion, well-represents the general experience. This brickwork, from the description and illustration, does not appear to be as even nor as smooth as that for which it is customary to use the coefficient $n = 0.013$. The latter figure usually requires struck joints and a very even surface. For brick sewers we now generally estimate $n = 0.015$, although this higher coefficient is intended to compensate also for some resistance caused by the presence of suspended and dragging matter in the flowing sewage.

When comparing and determining the coefficient n of roughness in the Kutter formula, we should not forget that in brick conduits this coefficient slightly increases with the velocity. That is, in the same conduit it will be a little greater for a velocity of 3 ft. per sec. than for one of ½ ft. per sec., although the character of the wetted perimeter is just the same.

It is novel to the writer to read of the effect of blasting, suggested by the author as increasing the degree of roughness. The facts seem clear to justify the suggestion, but it would also seem important to prevent such a result, both on account of the roughness and mainly on account of preserving the integrity of the brickwork.

T. C. Phillips, M. W. S. E.: I have read Mr. Ericson's paper with much interest and think he has submitted some very valuable data on the coefficient of roughness of the wet perimeter of brick-lined conduits.

The engineer and hydraulician are constantly confronted with greater problems, and reliable data of this character will undoubtedly tend toward greater economy in design.

In this discussion I have attempted to analyze the results obtained by Mr. Ericson and to bring out those in which he reposes greatest confidence.

In the 10 ft. section from the intake crib to the shore shaft at Kingsbury street, a distance of 20,485 ft., Mr. Ericson obtains a value of 0.01455 for the coefficient of roughness, n of Kutter's formula. This section of tunnel was lined with sewer brick laid in cement mortar. The mortar joints were not scraped or pointed but were made with no unusual roughness. The inside surface was fairly even and regular, or, to use the words of Mr. Ericson, "it was a sample of good brick sewer or tunnel work." The value of n

obtained is slightly greater than the value of *n* given for brickwork in Kutter's formula, which is 0.013.

The "Kingsbury-Green Street" section is a continuation of the "Intake Crib—Kingsbury Street" section and is also a brick-lined 10-ft. section. Its length is 2,216 ft. The coefficient of roughness *n* obtained was 0.01347. This section when completed was in much better condition than the "Intake Crib—Kingsbury Street" section.

Mr. Ericson suggests that, this section being shorter and the slope smaller, slight errors in the readings might be introduced more easily than in the longer sections. However, he states that gauging No. 4, giving *n* equals 0.0133, and gauging No. 5, giving *n* equals 0.0136, may be considered very reliable.

The section from Green to Keith streets is an 8 ft. brick-lined conduit, 3,328 ft. long. Here the brickwork along the entire section is described as being more or less disturbed by blasting in the tunnel during construction, which Mr. Ericson believes accounts for the large coefficient of roughness *n* equals 0.01552.

The same may be said of the remaining 18,855 ft. of this tunnel to Springfield Avenue Pumping Station, where a coefficient of *n* equals 0.01493 was obtained.

From Green Street to Carroll Avenue shaft and from Carroll Avenue to Central Park Avenue Pumping Station, a distance of 19,856 ft., a coefficient of roughness of 0.0138 was obtained. The point Mr. Ericson brings out in this branch of the tunnel was the fact that the brickwork was laid after the excavation was completed, and that there was no disturbance of the mortar joints or of the even regular lines of the tunnel.

The gaugings made on the section from the intake crib to Kingsbury Street, on the "Green to Keith Street" section, and on the "Keith Street to Springfield Avenue" section, gave coefficients of roughness for *n* of 0.01455, 0.01552, and 0.01493 respectively. The reliability of these results is somewhat questioned by Mr. Ericson, on account of disturbances in the regularity of the tunnel lining due to blasting.

It appears from the data submitted that the more reliable results are those of the "Kingsbury-Green Street" section and the "Green Street-Central Park Avenue" section. The three sets of gaugings on these sections give coefficients of roughness for *n* of 0.01347, 0.01382, and 0.01385.

Taking an average of the three more reliable sets of gaugings, Mr. Ericson obtains an *n* of about 0.0137. He is of the opinion, however, that with good brick laid in a workmanlike manner, true to line, not disturbed, and with flush joints, a coefficient of roughness of 0.013 for *n* in Kutter's formula is attainable.

Perhaps Mr. Ericson should embrace in his statement an allowance for reasonably low mean velocities of flow, as higher velocities would result in slightly higher coefficients.

The deduction that is made is analogous to the results of the tests made on the Sudbury Conduit in Massachusetts. This is a horse-shoe tunnel with greatest depth of 7 ft. 7 in., and a greatest width of 9 ft. 0 in. The lining is of hard brick and has a smooth surface with mortar joints well made and with surface carefully scraped.

Fteley & Stearns are authority for about sixty tests for the coefficient of roughness on sections of this brick conduit, and the results obtained show values of *n* in Kutter's formula approximately 0.012. One set of experiments on a 600-ft. section of this conduit gave values of about 0.011 for *n*. These results are for smoother surfaces than those for which Mr. Ericson makes his determinations of 0.0137 for *n*. The mean velocities also were generally a little less than 2 ft. per second as against mean velocities of about 2.4 ft. per second in the Sudbury Conduit tests.

It may be of further interest here to give the results of a few tests made by Mr. J. P. Eddy under my direction on 24 in. and 36 in. cast iron mains. The mains I speak of are discharge lines running west from Sixty-eighth Street Pumping Station, Chicago Waterworks.

The following table gives the data and the results obtained from these tests:

Table No. 1.

TEST OF CAST IRON WATER PIPE UNDER PRESSURE

To Determine Value of "*n*" in Kutter's Formula.

Location of Water Main.	Date laid.	Date of test.	Diameter in feet.	Length in feet.	Mean hydraulic radius in feet, "*r*."	Hydraulic gradient or slope per 1,000 feet, "*s*."	Mean velocity in feet per sec. "*v*."	Coef. *C* in formula $v = C\sqrt{rs}$.	Coef. of roughness, "*n*."
Main in 67th st. and 68th st. from Stony Island ave. to Cottage Grove ave........	Dec. 1890	May 1907	3	5,950	0.75	0.0015	3.70	110.44	0.013
Main in 66th st. and 67th st., from Oglesby ave. to Woodlawn ave.	June 1889	May 1907	3	7,975	0.75	0.00215	4.45	110.97	0.013
Main in 66th st. and 67th st. from Oglesby ave. to Woodlawn ave.	1898	April 1911	3	7,975	0.75	0.00215	4.45	110.72	0.01301
South Main in 68th st. from Oglesby ave. to Stony Island ave.	1893	April 1911	2	4,357	0.50	0.0032	4.40	110.00	0.0122

The mean velocity was obtained by measuring the flow with a pitometer. Simultaneous measurements of the flow were made at the ends of the pipe line to insure against losses in the line. The differences in pressure were carefully made with accurate gauges and corrected for slight differences in elevation.

I have not had an opportunity to examine the interior of the water mains tested, but from a general knowledge of the condition of the inside of water mains in Chicago, gained from many pipe traverse surveys and also from an inspection of numerous cases of pipe in use for varying long periods, I believe I may say that a comparatively clean inside condition may be expected. The slight deposit which is found is of a more or less gelatinous nature and probably has little effect.

The mean velocities of the mains under test ranged from 3.7 to 4.45 ft. per second, giving a coefficient of roughness of 0.013 for *n* in the 36 in. pipe, and a value of 0.012 for *n* in the 24 in. pipe. These mains were in service from 9 to 18 years when tested. The 24 in. main, 18 years in service, gave a value of 0.0122 for *n*.

The two tests made on the 7,975 ft. of 36 in. main in 1907 and 1911 show a slight decrease in *C* and an increase in *n* for this main, but the results are not sufficient, however, to be taken as an indication of increasing roughness.

C. B. Burdick, M. W. S. E.: For a number of years I have been quite interested in this subject. About two years ago we completed a tunnel for the water supply at Gary, 3 miles in length and about 6 feet in diameter. We made quite elaborate provisions for obtaining its friction coefficient when completed; but, unfortunately, we encountered many of the same difficulties that Mr. Ericson has overcome with so much patience, and our facilities for carrying out the test were not sufficient to warrant us in going through with it. There was pumping machinery of only about 20,000,000 gallons ultimate capacity for the 6 ft. tunnel, which would have produced a drop in the 3 miles of tunnel so slight that in our opinion it was not practicable to make a test that would have given any valuable data. The variations which Mr. Ericson has noted in Chicago tunnels, due to bringing the water to rest in the shafts, was particularly accentuated in the Gary tunnel, from the fact that centrifugal pumping machinery was installed, which was very difficult to start and stop gradually, and the fluctuations were much greater, apparently, in the ordinary starting and stopping of the machinery (perhaps also due to roughness on the lake), than was noted in Mr. Ericson's observations. I recall that upon shutting down the machinery in the pumping station it was customary for the water to rise and fall in the pump shaft some 6 or 7 ft., and oscillate back and forth for a very long time. For that reason we gave up making the test.

I was very much interested to note the low friction coefficient—0.013 approximately or 0.014— that Mr. Ericson obtained. There had been more or less data, I think, not so carefully worked out as that which Mr. Ericson has presented, which seemed to indicate somewhat higher values under similar circumstances in this vicinity. I had not supposed that ordinary inspection would be effectual in obtaining such apparently favorable values as were obtained in the tunnel described in this paper. The tunnel at Gary was a concrete tunnel and there was some discussion at the time that the tunnel was completed in regard to finishing the surface. That seems to be a bone of contention wherever concrete is used, and I have little doubt that if the tunnel was tested in the shape in which it was first completed, the coefficient would have been much higher than the figures which Mr. Ericson has named. We investigated, at the time this matter was under discussion, all the data that we could find. Quite a little have been collected by the Water Board at Los Angeles, not only on tunnels but on open conduits, concrete lined. Such data as we could secure, and a very careful examination of our tunnel lining, seemed to indicate that we might expect values of n as high as 0.018 or 0.020 for the work as it was first completed. Later the tunnel was plastered inside, and I have little doubt that the tunnel as finally completed would have shown results closely comparable with good brickwork. It is difficult to get a good, smooth lining, from a hydraulic standpoint, in a concrete-lined tunnel without plastering it. That sort of construction work must be done rapidly. Miners must make their distance and concrete men must make up their distance and keep the lining up with the heading. The result is that it is almost impossible to work in all the refinements in the surfaces of the concrete that are practicable with work done above the ground. Lagging or forms that are used over and over again, section after section, become very rough, and the fit of frames or braces is not good, with the result that there are inequalities in fitting one section of lagging to the next section. That is particularly important to the flow of water in a tunnel, for it makes a rib around the lining, which has a very detrimental effect on the coefficient of the tunnel. But with reasonable care I think most of the inequalities of concrete work can be overcome.

I was interested in what Mr. Phillips had to say in regard to the friction coefficient in cast-iron pipe. It has not been my custom to use the Kutter formula on pipes. I had practically accepted Weston's tables as the gospel of cast-iron pipe, and although I have made quite a number of comparisons, and quite a number of tests of the friction in cast-iron pipe for one purpose or another, I have never had occasion to work it back into the value of n in Kutter's formula. The Weston tables, as computed (I believe by the Darcy formula), have been borne out in my experience a number of times. I think four or five times I have had occasion to test new pipe that checked up remarkably closely with Weston tables. There is a table accompanying the Weston tables which purports to show a correction in the friction values due to age. I have had a number of opportunities to check old pipes and compare the results with these values, and while, as would be expected, the values on individual pipes vary materially, on the average they check very well. It is not uncommon, in my experience, to find pipes fifteen to eighteen years old in which the lost head in a given length was 50% more than new pipe of the same length. I recently had an opportunity to make some tests in a system where pipes about 6 in. in diameter were tested, of various ages, ranging from new up to old pipe. In every case the old pipe gave the higher friction losses. I have no doubt that in most cases this is true.

Mr. Sherman: It is worth while, I think, to note that in Mr. Ericson's paper the coefficient of *n* is greater for that length between the crib and Kingsbury Street than it is for the stretch between Kingsbury and Green streets. One length is twenty times as great as the other. The coefficient for the greater length is the greater. I think that is quite important. If we will average the two, —one is 2,000 ft. and the other 20,000 ft.,—the longer length should have about ten times as much weight as the short one. I would consider that the coefficient derived from the longer length is probably of far greater accuracy.

A. Bement, M. W. S. E.: I have no special discussion to offer but as this paper is such a valuable one and of a character that we seldom have presented, I should like to call attention to the excellent effort on the part of the author in preparing the paper, and to say, as a member of the Society, that I think we should appreciate the care which Mr. Ericson has taken in his experimental work.

Mr. Sherman: I am sure that those who have had anything to do in the line of hydraulic research work appreciate the great care that is necessary to obtain results that are to be of any value whatsoever, and, as has been mentioned, of the tunnel at Gary about getting water levels. The difficulty that I have had in attempting to get certain coefficients from the Main Drainage Canal of the Sanitary District makes me, for one, appreciate the labor that has been put into this paper.

C. C. Saner, ASSOC. W. S. E.: I have made up some figures along the line of work mentioned by Mr. Burdick, on concrete-lined tunnels. In the last few years all the tunnels that the city has built have been concrete lined, and the tunnels that I worked on were carefuly plastered, resulting in a good finish. I would judge that the low value of *n* mentioned by Mr. Ericson could be obtained.

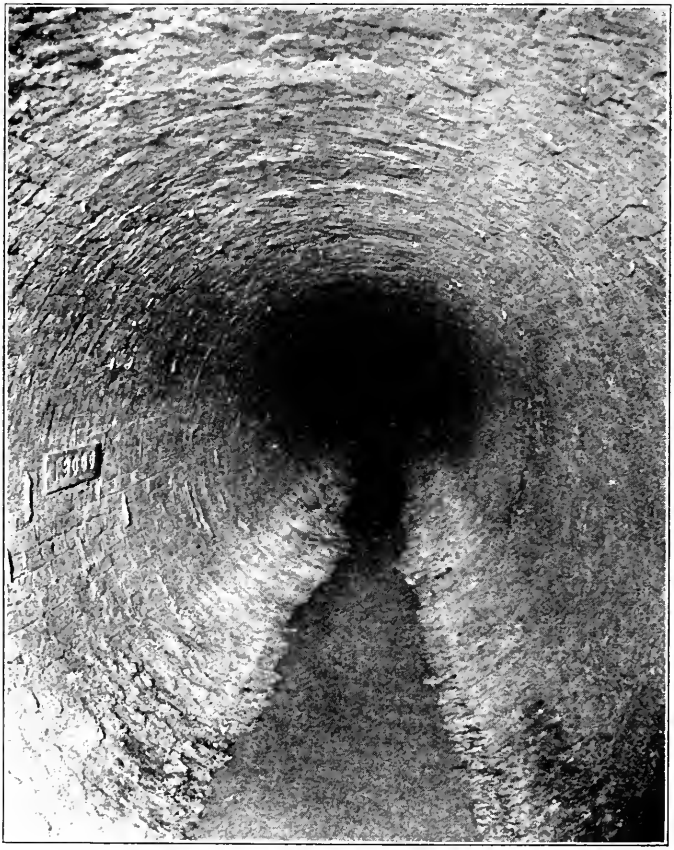
The question has arisen as to whether it pays to plaster a tunnel or leave the section larger. I have taken a slope about the same as on the southwest land tunnel and the same discharge, 91 cu. ft. per second, and using a value of *n* equals 0.013 we would require an 8 ft. tunnel; using a value of *n* equals 0.015 we would require an 8½ ft. tunnel. Taking the cost of the concrete at 20c a cubic foot,—that is $5.40 a yard, which is very close to what it costs,—the excavation at 8c a cubic foot, or $2.16 a cubic yard, and the plaster coating at 4c a square foot, I find that the cost of those items alone on the 8 ft. section plastered is $12.93, and on the 8½ ft. section, not plastered, is $12.90.. We might say that the two are the same. So if we should find out by experiment that the value of *n* of a concrete-lined tunnel that is plastered is more than two-thousandths below one that is not plastered, it pays to plaster, as the same discharge will be obtained at less cost. I have figured only for earth excavation. I think my costs are very close, from the experience I have had on this work; and in designing a tunnel, especially a tunnel such as Mr. Ericson has described,—some of it in rock,—all these costs should be given careful consideration. Of course it would be different in a rock section, as the cost of excavation would run up to $4.50 or $5.00 per cu. yd., and before any nicety is gone into to get a low value of *n,* I think that the relative costs should always be investigated.

Our experience has been that in the lower quarters of the tunnel the concrete will be rough. We can generally obtain a fairly smooth concrete in about the upper two-thirds of the section, but it is impossible, by any means that we have ever found, to get a smooth concrete in the lower third. If a plaster lining is to be used in a tunnel, it is better to have the section rough all the way round, as the plaster will adhere better. I do not think it is possible to get a smooth finish in the bottom of any tunnel without plastering. I think that it is like a great many other engineering values that have been replaced by new ones, that this value of *n* will have to be obtained in concrete sections now as all construction is in concrete at present. On the southwest land tunnel I presume there will soon be a special test made.

Mr. Burdick: There is one point I neglected to mention which I think it will be well to bring out: that is, in all probability the masonry-lined conduit does not deteriorate in carrying capacity in the same amount that the iron conduit or pipe deteriorates. The roughness in iron pipes is caused by a chemical reaction between water and iron, producing lumps or tubercles; this does not occur in the masonry-lined conduit. I was informed by one of the engineers connected with the city that recently an opportunity was offered to examine the interior of a masonry-lined conduit that had been in use for many years. I should like to see a description of the condition of this old tunnel added to this discussion. I understand that after the tunnel had dried out, the masonry work appeared to be about as smooth as newly-constructed masonry; that is, there was no action or deposit that would seriously affect its coefficient of roughness.

H. W. Clausen, ASSOC. W. S. E.: Mr. Burdick's last statement makes it rather fitting for me to say a few words in regard to the old cross-town tunnel which runs from Chicago avenue and Lake Michigan to Twenty-second street and Ashland avenue. It was put into service in the year 1874, I believe, and was in continuous service until about a year and a half ago, when the new Blue Island avenue tunnel replaced it. In connecting the Twenty-second Street Pumping Station with the Blue Island Avenue tunnel it was necessary to put certain bulkheads in this old cross-town tunnel, and we had occasion to pump it out. We pumped out the section between

Jefferson and Van Buren streets and Chicago avenue and the lake. Believing that it would be of interest to go through the tunnel with a party and see its condition after about thirty-seven years' continuous service, I did so and took several photographs. We found, after a careful examination, that the condition of the brickwork was perfect. There was not a single place, except near one shaft in the bottom of the tunnel, where any of the mortar was washed out of the brickwork. There was very little silt or sediment in the tunnel. It was very slippery, but I attributed the greater part of the silt that was found in the bottom of the tunnel to the fact that the water had been stationary so long before being pumped out that the silt in the water had an opportunity to settle. I believe that the tunnel was absolutely self-cleansing under ordinary flow.



Old Crosstown Water Tunnel.

I was much impressed with the character of the brickwork and with the way it had endured. In my opinion, the depreciation was practically nothing after thirty-six or thirty-seven years of continuous service.

Mr. Saner: I had occasion to go into the Peck Court tunnel in the same way after it was pumped out, after we had connected in Jefferson street near Harrison street, and found exactly the same conditions there. It might be of interest to say that this old tunnel had a westerly direction to Harrison Street Pumping Station, and at Van Buren and Jefferson streets the old cross-town tunnel that Mr. Clausen has just referred to is connected with this Peck Court tunnel by a by-pass in Jefferson street, which was 5 or 6 ft. in diameter. We found this by-pass about half full of silt. During the survey for this Polk Street tunnel, one of the men, while measuring up the shaft at Harrison and Jefferson streets, was overcome with gas, and lost his hat. A year and half after that his hat was found down in that by-pass and it looked to us as if anything in suspension is carried in there by eddies and deposited.

Mr. Clausen: I think that silt can be attributed to the fact that the velocity through that connection is not very great, because it is only a by-pass connecting the Carter Harrison crib, or, as it was known at that time, the old two-mile crib and the present four-mile crib; the Harrison Street and the Fourteenth Street pumping stations both take most of their water through the four-mile tunnel, and it is only in times of stress that much water is taken through this connection. Evidently the connection is plenty large enough and the velocity is so low that silt has continued to deposit and fill up the tunnel.

Mr. Sherman: I take it that this is more in the nature of a deposit due, as Mr. Clausen says, to low velocity rather than to any deposit or tuberculation on the sides of the conduit.

C. D. Hill, M. W. S. E.: I desire to express my appreciation of this paper, and the great care and attention necessary to produce it. I hope that we may have a similar paper on the concrete tunnels, and when that is presented I will perhaps offer some discussion on the subject of concrete linings in sewers. Mr. Ericson states that it is attainable to build bricklined conduits where the coefficient of friction will be as low as 0.013. That is perfectly true, but it is not practicable to build sewers where we can get so low a coefficient, and Mr. Ericson's own experience with these tunnels shows that it was not practicable to get it in these particular water tunnels, because of unforeseen occurrences. In sewers, particularly where there are manholes every 150 ft., or more frequently, and where there are junctions with houses where the water is flowing in and eddies are forming every few feet, it really is absurd to expect such results. It is customary, and I have used the rule myself, to compute capacities of sewers based upon this coefficient n equals 0.013. I have reformed slightly and now I use 0.014, but actually I have no doubt that 0.015 or possibly 0.017 would be still more nearly correct.

G. L. Clausen, M. W. S. E.: In my opinion these varying cross-sections of the shafts and disarrangements of the cross-sections in the conduit have more of a bearing upon the increase value of *n* than is considered in Mr. Ericson's paper. The reason for this opinion is that in one case I had a sewer about five miles long, of a uniform diameter of 6 ft., where the manholes do not enter into the obstructions. The manholes are only 3 ft. in diameter, and as is well known we do not consider that the sewer would run full, so that it was a uniform conduit, without any obstruction so far as change of velocity is concerned. Now this sewer was figured with *n* at 0.012, and was built about twenty years ago. Figuring the rainfalls in the usual manner, that sewer has never run any fuller than it ought to with the coefficient of 0.012. That is one of the reasons that I believe we are generally using, in brickwork, a higher coefficient of *n* than is necessary. I cannot prove it, but if I should use 0.013, that is about as far as my judgment would allow me to go in brickwork. As far as concrete construction is concerned, I have the idea, which I hope later on I shall be able to prove, that we should get a lower coefficient of friction in concrete sewers, provided they are properly plastered; that is, the inner surface is properly treated by means of filling any of the interstices or vacancies that are left between the stone and the mortar. I have the idea that concrete will give a less value, which I hope we shall be able to prove by subsequent experiments.

Mr. Phillips: I was interested in the statement Mr. Burdick made in reference to the method of calculating the coefficient of roughness for cast-iron water pipe. He said he generally used the Darcy formula, as given in Weston's tables for determining friction in water pipe, for the reason that in many tests he had made, he obtained results that agreed closely with the tables.

I made the tests referred to above in 1907, to determine the mean velocity and the friction losses in the 24 in. and 36 in. discharge lines running west from the Sixty-eighth Street Pumping Station, Chicago Waterworks.

A comparison of the results found by test with those given in "Weston's Friction of Water in Pipes," is shown in the following table:

The loss of head due to friction in these discharge lines with long service agrees closely with the losses for new and clean pipe as given in Weston's tables. The small friction losses with water mains in Chicago is a condition peculiar to the character of the water. There is practically no tuberculation or oxidation such as is found in the Boroughs of Manhattan and Brooklyn, New York City. I made a great many pipe traverse surveys in Brooklyn and found ratios of mean to maximum velocity of about 0.77 to 0.81, and in a few instances in large pipe as low as 0.73. In Chicago

Table II.

COMPARISON OF FRICTION LOSS IN CAST IRON PIPE, FOUND BY TEST WITH FRICTION LOSS GIVEN IN WESTON'S TABLES.

Location of Water Main.	Date laid.	Date of test.	Diameter in feet.	Length in feet.	Loss of head in feet.	Mean velocity, in feet.	Friction loss by test per 1,000 feet.	Friction loss by Weston's tables, per 1,000 feet.
North Main in 68th st. from Oglesby ave. to Stony Island ave............	1893	April 1911	2	4,409	13.81	4.40	3.13	3.11
South Main in 68th st. from Oglesby ave. to Stony Island ave............	1893	April 1911	2	1,357	13.73	4.40	3.15	3.11
Main in 67th st. and 68th st. from Oglesby ave. to Woodlawn ave......	1889	April 1911	3	7.975	17.13	4.45	2.14	2.10
North Main in 67th st. from Stony Island ave. to Cottage Grove ave...	1893	May 1907	2	5,950	8.74	3.00	1.47	1.45
Main in 67th st. and 68th st. from Stony Island ave. to Cottage Grove ave....	1890	May 1907	3	5,950	8.93	3.68	1.50	1.43

the ratio of mean to maximum velocity varies from 0.83 to 0.90 with common values of about 0.85 to 0.86.

I give these results to show that conduits and pipe in Chicago, carrying clear water, are generally little affected by accumulations on the inner surface after being in service for some time. This fact is perhaps another reason why Mr. Ericson may reasonably expect to obtain a coefficient of roughness of 0.013 for *n* under the conditions he has given.

Mr. Hill states that he believes Mr. Ericson's deductions are too high, as they do not coincide with results he has found in sewer work in Chicago. He has promised the Society a paper on this subject which I am sure will be a valuable one.

The difference between the effect of sewage and clear lake water on the interior roughness is quite important, and I believe will make considerable difference in such a comparison.

In the new water-supply tunnel at Gary, Ind., designed by Alvord & Burdick, considerable attention was given, I understand, to obtain a smooth interior lining. The tunnel was carefully washed with cement when completed. The additional cost incurred and the effect of this finish would undoubtedly be of much interest.

CLOSURE.

The Author: With reference to Mr. Hill's remarks; of course, I made a statement in my paper to the effect that I do not expect a coefficient of 0.013 including shafts and bends and so forth, but I wish to say distinctly that if we eliminate those causes of lost head, I believe that a coefficient of .013 is easily obtainable by using care in the construction of the tunnel.

Referring to the discussion by Mr. Artingstall, the experiments which he refers to give some interesting figures. Some of his observations were made as early as May, 1870. Mr. Artingstall did not apply Kutter's formula to his observations, probably on account of this formula not being much known in America at that time.

In order, however, to draw some comparisons between these early experiments and the more recent ones, I requested Mr. F. A. Smith, Assistant Engineer of the Bureau of Engineering, to make the observations as published in Mr. Artingstall's paper a basis of computations, reducing them to *n* as determined by Kutter's formula:

The following table shows a summary of these tests reduced to the elements of Kutter's formula:

Table No. 1.

Gaugings in 5-foot lake tunnel, 10,500 feet long with no intermediate obstructions.

Mean Head	Mean Velocity	S	R	C	n Scaled	Date of Observation
1.995	1.713	0.00019	1.275	108.4	0.0141	May 27, 1870
1.891	1.7025	0.00018	1.275	111.3	0.0136	May 28, 1870
1.6857	1.7708	0.000161	1.275	123.6	0.0124	May 29, 1870
1.6703	1.712	0.000159	1.275	120.31	0.0127	May 30, 1870

These results make a fairly good showing, though the coefficient *n* varies considerably, while considering the slight variation in head and velocity; they should be about equal. The average value of *n* thus obtained is .0132, and gives about the same results as the tests for certain lengths of the tunnel described in the paper under discussion.

Table No. 2 shows a tabulation of nine observations on the 7.1 ft. tunnel between the Chicago Avenue and Ashland Avenue pumping stations, a distance of 20,500 feet.

Table No. 2.

Mean Head	Mean Velocity	S	R	C	*n* Scaled
.321	.47179	0.000015	1.775	91.4	0.0162
.340	.51648	0.0000165	1.775	95.5	0.0155
.403	.55809	0.0000195	1.775	94.74	0.0156
.456	.60345	0.0000222	1.775	96.12	0.0154
.524	.62972	0.0000254	1.775	93.84	0.0158
1.174	.95728	0.0000571	1.775	95.16	0.0155
1.274	1.0328	0.0000621	1.775	98.39	0.0151
1.567	1.1428	0.0000763	1.775	98.18	0.0151
1.721	1.2062	0.000084	1.775	98.9	0.0150

The above results show good uniformity of the coefficient *n*, the average value being 0.01547.

Mr. Artingstall ascribes the greater loss of head in this 7 ft. tunnel to 17 shafts and chambers forming obstructions to the flow.

During November, 1909, when the Blue Island Avenue Land Tunnel was being placed in service, replacing the old crosstown tunnel, it was possible to inspect this old tunnel between the working shaft at Jefferson and Van Buren streets and the working shaft at Chicago avenue and Lincoln parkway, the water being pumped out between these points.

The inspection made by Messrs. H. S. Baker and H. W. Clausen, Assistant Engineers of the Bureau of Engineering, revealed the fact that, at the foot of the Illinois Street working shaft, and in the tunnel itself on both sides of the shaft, considerable rubbish was found in the way of old brickbats, iron hoops, an old wheelbarrow, and an old shovel, as well as the timber sills of the old elevator guides being still in place. A photograph of this point is appended hereto with the wheel-barrow removed from the picture. It was also noticed that the station numbers were placed on the springing line every 100 ft. through the tunnel. These markers were about 6 in. square, made of pats of natural cement, with the station numbers stamped into the pats. These features undoubtedly have an influence upon the high value of *n* found by Mr. Artingstall.

The loss of head which he gives as $\frac{2.04\ V^2}{2g}$ for shafts and chambers alone is, therefore, evidently too large, for if this formula is, for instance, applied to the ninth observation, it would reduce the coefficient *n* to 0.0118, which is undoubtedly too low and which would be still lower if deductions for the other obstructions described above were to be taken into consideration.

The condition of the brickwork after about thirty-five years of service showed no indication of deterioration. The joints were all in perfect shape, except in a single place in the bottom of the tunnel where the cement was washed out of the same.

The tunnel was remarkably free from silt throughout, the deposit shown in the pictures probably being due in a large degree to settlement of silt while water was still in the tunnel previous to pumping out.

Judging from the appearance of this tunnel, it was in all respects as good on the day of examination as it was on the day built, showing practically no depreciation.

The observations of the flow in the Fullerton Avenue conduit in 1879 are shown in:

Table No. 3.

Obstructions to flow: 16 shafts 6-ft. diameter, 2 shafts 12-ft. diameter, and 2 vertical **curves 45-ft. radius.**

Observed Head	V	S	C	n
0.82	1.39	0.00009	84.5	0.021
0.97	1.66	0.00011	92.5	0.019
1.32	2.02	0.00015	97.3	0.018
1.55	2.13	0.00017	94.8	0.019
1.69	2.14	0.00019	88.3	0.020
1.96	2.256	0.00022	86.5	0.020

The variations in the coefficient *n* are here very marked, which would indicate errors in observations.

Mr. Artingstall recommends that the mean loss of head due to the sixteen 6-ft. and two 12-ft. shafts be taken at $\frac{0.99\ V^2}{2g}$ for each shaft. Applied to the sixth observation, this makes the loss due to the obstructions 1.07 ft., leaving 0.89 ft. as friction head for the 8,900 ft., or S = 0.0001. This will give a value to the coefficient C = 130.4 instead of 86.5 and the coefficient n = 0.0136 instead of 0.020. This would indicate a much more reasonable result.

One interesting factor of Mr. Artingstall's paper is the comparison drawn between his observations and results obtained by applying the formulae of Hawksley, Blackwell, Prony, Eytelwein, D'Aubison, and Weisbach.

Referring to the gaugings made by Mr. C. F. Schulz, Chief Engineer of the Water Department of Cleveland, I was connected, in a consulting capacity, with the tunnel case in said city. In this connection it became advisable to obtain some information in regard to the flow of water in the water tunnel there, and the gaugings were made by him at my request. The tunnel has been described in Mr. Schulz's discussion.

This tunnel, before being completed, was abandoned by the contractor and afterwards finished by day labor by the city of Cleveland. That part of the tunnel constructed by the contractor proved quite leaky, and the city, upon assuming charge of the work, found this portion, which constituted by far the greater part, about one-third filled with silt and fine sand. When the tunnel was completed this silt was removed, the tunnel cleaned, and the water speedily let in.

The gaugings described by Mr. Schulz were made October 27, 1909. The rate of flow was determined by the pump revolutions and the proper allowance made for slip. He had occasion afterwards to check the slip by Venturi meters, and his estimate of the same has been used, and is considered to be close to the facts. The head was obtained from gauge readings obtained by a 12 in. Bristol water-level recording gauge at the crib and by a Builders' Iron Foundry recording gauge at shaft No. 5.

The elevation of these gauges was established by frequent lake-level readings on smooth, calm days.

I have divided the experiments referred to by Mr. Schulz into four parts, since the amount of pumpage was increased or decreased at certain intervals.

The following table gives the results of the gaugings of October 27, 1909:

Table No. 4.

No.	Time	Average Velocity, ft. per sec.	Head	R	S	C	n
1	8:00 a. m. to 11:30 a. m.	1.579	2.193	2.266	0.000084	**114.3**	**0.01466**
2	9:15 a. m. to 11:30 a. m.	1.578	2.235	2,266	0.000086	**113.2**	**0.01480**
3	11:45 a. m. to 1:00 p. m.	1.912	3.478	2.266	0.0000133	**109.9**	**0.01533**
4	1:15 p. m. to 5:00 p. m.	1.574	2.251	2.266	0.0000865	**112.5**	**0.01481**

As I had some data of gaugings made by Mr. Schulz on October 26, 1909, I also present the results obtained from these, and shown in Table No. 5:

Table No. 5.

No.	Time	Average Velocity, ft. per sec.	Head	R	S	C	n
1	8:00 a. m. to 9:45 a. m.	1.58	2.193	2.266	0.000081	114.4	0.01467
2	10:00 a. m. to 11:00 a. m.	1.96	3.36	2.266	0.00013	114.6	0.01475
3	11:30 a. m. to 12:30 p. m.	1.206	1.422	2.266	0.000054	108.4	0.01522
4	1:00 p. m. to 4:00 p. m.	1.57	2.379	2.266	0.000091	109.1	0.01535

The average value of the coefficient of roughness n from the experiments of October 27, 1909, equals 0.0150, and from the experiments of October 26, 1909, equals 0.0149. The sudden changes in the pumpage, without allowing sufficient time for the water to assume the resulting slope conditions, probably affected the results of these gaugings to some extent.

From information I obtained in reference to the material used, as well as to the workmanship, as far as the interior smoothness of this tunnel is concerned, and irrespective of the fact that there were many joints with insufficient mortar, so that sand and silt could run into the tunnel, I believe that a coefficient $n = 0.0135$ would be nearer the correct value than the values obtained from the gaugings.

I am, therefore, of the opinion that from the time of the opening of this tunnel to the date of these gaugings, there had been an accumulation of silt in the tunnel corresponding to an average depth of about one foot along the entire length of the tunnel. If this is assumed to be a fact, the above gaugings will give a value C in formula $V = C \sqrt{RS}$ of about 125 and of n in Kutter's formula of 0.0135.

This is, of course, only an assumption, but I feel confident that the value of the coefficient of roughness n for this tunnel is considerably less than that obtained from the gaugings.

I hope I shall have an opportunity to make some experiments on concrete-lined tunnels, now nearing completion, in the not too far distant future.

AN ANALYSIS OF THE STRESSES IN GUY WIRES

W. M. Wilson, M. W. S. E.

Presented May 3, 1911.

Some time ago the writer received an inquiry in regard to the stresses in steel wires such as are used for guys for steel stacks. Upon investigation he was unable to find any treatment of the subject and began an investigation which resulted in the following demonstration.

Steel stacks which are not self-supporting are usually supported by one or more sets of wires, each set consisting of four wires evenly spaced as seen in the plan. Such a stack is shown in Fig. I.

Let OC, Fig. 2, represent such a stack and let AC and BC be two of the wires lying in the plane of the paper. With OC in a vertical position, and with no horizontal force tending to overturn the stack, the two wires AC and BC will assume the same form. Each will exert a force at C, but under the conditions assumed the horizontal component in AC will be just equal but opposite in direction to the horizontal component in BC, so that the two acting together will have a horizontal resultant equal to zero and will therefore exert no horizontal force upon the stack. Suppose that some external force such as the wind acts upon the stack and moves it to some new position such as OC'. AC now occupies the position AC' and BC the position BC'. By inspection it is seen that the horizontal component of AC has been increased and that of BC decreased. The two acting together now exert

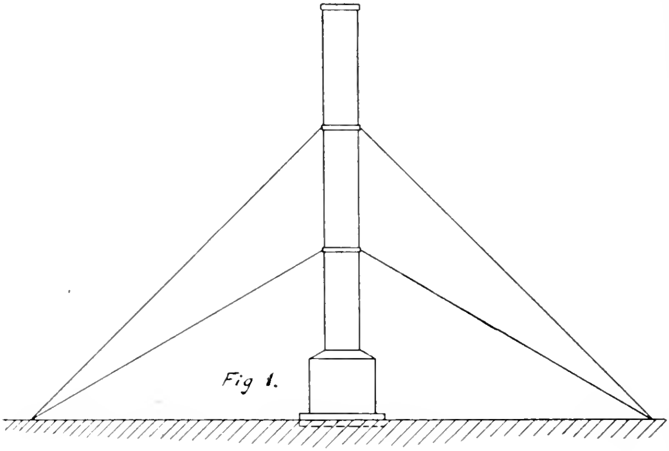


Fig 1

upon the stack a horizontal force equal to the difference between the horizontal components of the stresses in the two wires. This force tends to return the stack to its original position and has been designated by the writer as the *righting force*. The guy wires produce this righting force when, and only when, the top of the stack moves out of the position which it occupies when no external force acts upon it.

It is evident that the less the initial stress in the wires the greater the displacement of the stack required to produce a given righting force, and also the lower the initial stress the greater the ratio of the righting force to the maximum stress in the wires. An analysis of the problem involves the determination of the relation existing between the four variables, initial stress in the wire, deflection of the stack, horizontal righting force, and the maximum stress in the wire. It was found that the mathematical relations between the quantities involved are so complex that the numerical solution of any specific problem would be impracticable. The writer therefore, undertook the solution of typical cases in order to get data from which curves could be platted for use in the solution of specific cases. The cases considered are those in which $a = 100$

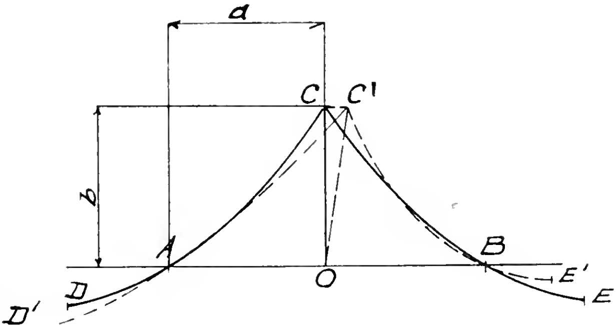


Fig 2

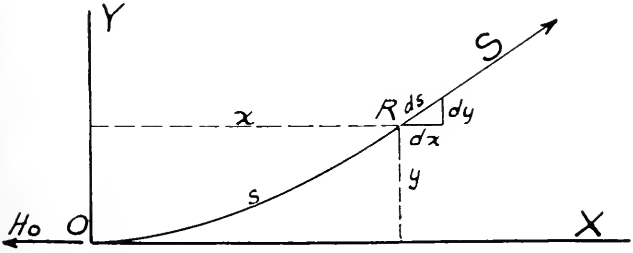


Fig 3

ft. $b = 50$ ft., and $a = 100$ ft. $b = 100$ ft. (see Fig. 2) when the horizontal component of the initial stress in the wire had the following values: 1020 lb. per sq. in., 1700 lb. per sq. in., 3400 lb. per sq. in., 6800 lb. per sq. in., 10,200 lb. per sq. in., and 13,600 lb. per sq. in. If the length of the wire whose weight is equal to the horizontal component of the stress in the wire be represented by c, the above stresses would correspond to values of c equal to 300 ft., 500 ft., 1000 ft., 2000 ft., 3000 ft., and 4000 ft. Plate 2 is for wires for which $a = 100$ ft. and $b = 100$ ft. It shows the relation between the deflection of the top of the stack and the resulting horizontal component of the stress in the wire. (For method of determining this relation see Appendix.) This curve was originally drawn for a wire having an initial value of $c = 1000$ ft. but can be used for other cases in which $a = 100$ ft. and $b = 100$ ft. by properly shifting the origin as explained in the Appendix. Plate 1 is the corresponding curve for the case in which $a = 100$ ft. and $b = 50$ ft. The portions of these curves to the right of the origin are for the taut wire, and the portions to the left are for the loose wire. Plate 3 was derived from Plate 1, and Plate 4 from Plate 2, as follows: Consider two points on the curve of Plate 1,—one a certain distance to the right of the origin and the other an equal distance to the left. The value of the ordinates of these two points gives the horizontal components of the stresses in the wires, and their difference gives the righting force resulting from a deflection represented by the abscissæ of the points chosen. In this way a number of points can be transferred from Plate 1 to Plate 3 and the curve on Plate 3 determined. This has been done for different values of the initial stress in the wire as indicated above for both Plates 3 and 4. The relation between righting force and deflection is given by the lower curves, and the relation between stress in the wire and deflection is given by the upper curves.

Referring to the equations of a catenary as given in the Appendix, it is seen that all of the quantities in the equations can be represented by lines. That is, if a catenary with a given value of c is drawn to a given scale, the same curve can be made to represent some other catenary by changing the scale of the drawing, but the value of c for the second catenary must bear the same ratio to the value of c for the first as the true value represented by any ordinate of the second catenary bears to the true value represented by the same ordinate of the first catenary. That is to say, while Plates 1 to 4 were originally drawn for cases in which $a = 100$ ft. $b = 100$ ft. and $a = 100$ ft. $b = 50$ ft., by properly changing the scale they will apply to all cases in which $a = b$ and $a = 2b$. For example, if $a = b$ equals n times 100 ft. the value of the maximum stress in the wire to be read from the curve would be the allowable stress divided by n, and the initial value of c to be used would be the given value of c divided by n, while the deflection and the righting force would be the values read from the curves multiplied by n. That is, the scale of the curve is changed by properly introducing the factor n.

As far as the writer is aware, but little is known regarding the value of the initial stress which is desirable. As it is increased, the righting force for a given allowable stress in the wire is decreased, and as it is increased the rigidity of the stack is increased. The value chosen should be such as to give the necessary rigidity and at the same time give as high an efficiency as possible. Some idea of the location of this happy medium may be obtained from a study of Plates 3 and 4. It is seen in both cases that as the initial value of c increases a high degree of rigidity is first obtained when c is about 1000 ft. With c much below this value, a considerable deflection is required to obtain any considerable righting force, as is seen from the curve for which $c = 500$ ft., while with $c = 1000$ ft. the ratio of the righting force to the stress in the wire is quite large. In view of this fact the writer suggests that $c = 1000$ ft. be taken as the proper value to use when the ratio of a to b varies from 1 to 2 and $a = 100$ ft. This value of c corresponds to an initial stress of approximately 4900 lb. per sq. in. when $a = b$, and 3900 lb. per sq. in. when $a = 2b$, for a steel wire. When $a = n \times 100$ ft., the proper initial value of c to be used to correspond to the above would be $n \times 1000$ ft.

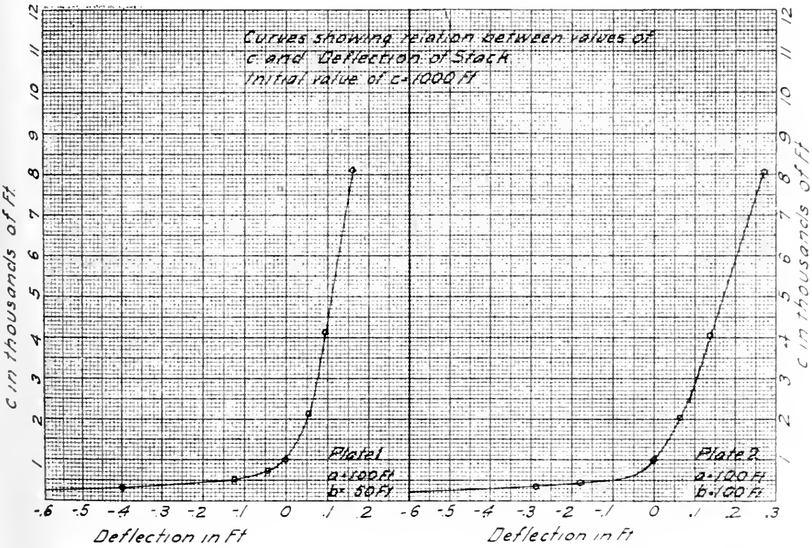


Plate 1. Plate 2.

Considering the numerical solution of a problem in which $a = 100$ ft. $b = 100$ ft. and the allowable stress in the wire is

16,000 lb. per sq. in., in which it is desired to find the proper size of wire to be used if the stack is acted upon by an overturning moment equivalent to a horizontal force of 6000 lb. applied at the point where the wire is fastened to the stack. Reading from the curve for c = 1000 ft. on Plate 4, the deflection is seen to be 0.110 ft. and the righting force is 9400 lb. per sq. in. The area of the section of the wire would be 6000 divided by 9400, or 0.638 sq. in. If the same problem had been solved by considering the wire on the taut side only, neglecting the loose wire, and considering it as acting at an angle of 45°, the righting force would have been 16,000 divided by the square root of 2, or 11,300 lb. per sq. in. That is to say, with an initial value of c = 1000 ft. the slack wire causes a loss of possible righting force of only 1900 lb. per sq. in., or 17%, and allows a deflection of only 0.110 ft. at a point 100 ft. above the base of the stack.

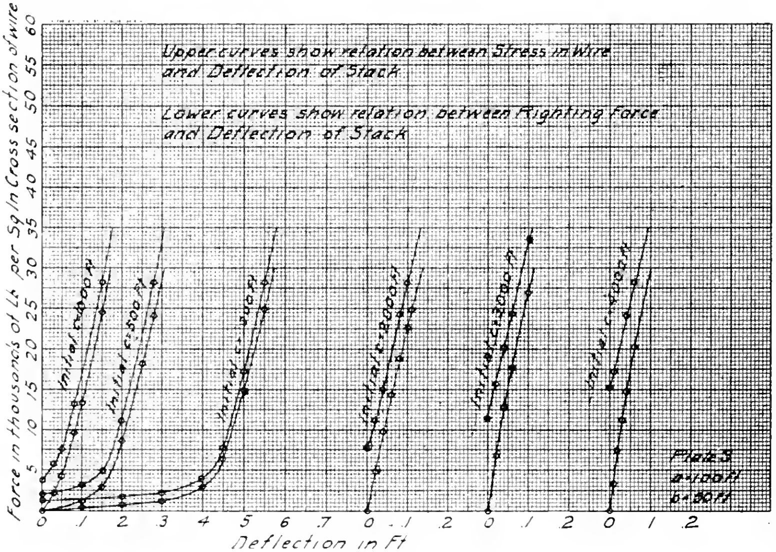


Plate 3.

Consider the solution of the above problem with the wire fastened to the stack at the same point as before, but take the ratio of a to b equal to 2. That is, a = 200 ft. and b = 100 ft. The initial value of $c = n \times 1000$ ft., in which $n = 2$. The value of c to be read from the curve is 1000 times 2 divided by 2, or 1000 ft., and the allowable stress to be read from the curve is 16,000 divided by 2, equals 8000 lb. per sq. in. Reading from the curve for c = 1000 ft. on Plate 3, the deflection is 2 times 0.052 = 0.104 ft., and the righting force is 4800 times 2, or 9600 lb. per sq. in. The area of the section of the wire is 6000 divided by

9200, or 0.625 sq. in. If the taut wire only had been considered and that considered as acting in a straight line having a slope of 1 to 2, the righting force would have been 16,000 divided by the square root of 1.25, or 13,560 lb. per sq. in. That is to say, with an initial value of $c = 2000$ ft. the slack wire causes a loss of possible righting force of 3960 lb. per sq. in., or 29%, and allows a deflection of 0.104 ft. Since the section of the wire is about the same, and the length of the wire is considerably greater in the second case than in the first, and as there is but little difference in the deflection in the two cases, it would seem that an arrangement of the wires so as to give a slope of 1 to 1 is better than with a slope of 1 to 2.

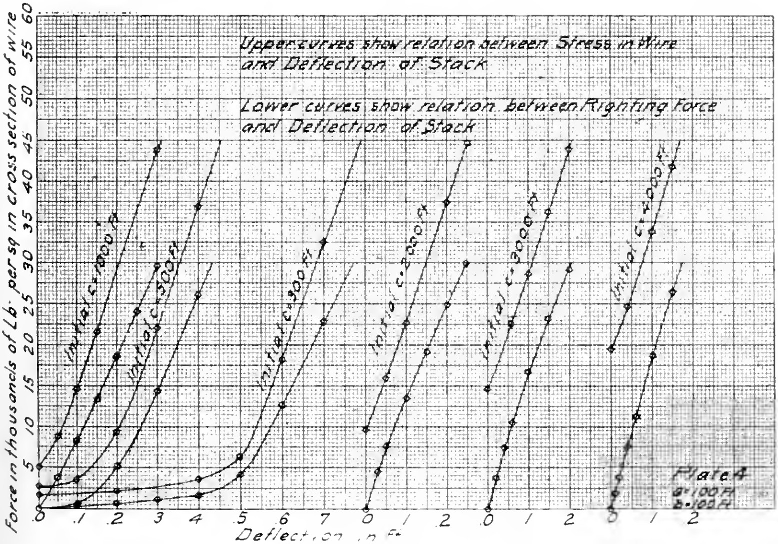


Plate 4.

In the first numerical case considered above, it was noted that the slack wire had but little effect upon the value of the righting force for a given stress in the wire, causing a reduction of only 17% from the maximum theoretical possible. If, however, the initial stress had been greater, the reduction in the righting force would have been considerably more. For example, take the conditions of the problem the same as before except that the initial value of c be taken at 2000 ft. Reading from the curve on Plate 4 for a stress in the wire of 16,000 lb. per sq. in., the deflection is 0.051 ft. and the righting force is 7600 lb. per sq. in., or a reduction of 3700 lb. per sq. in., or 32.7% below the maximum possible. If c had been taken equal to 3000 ft., the deflection would have been 0.012 ft. and the righting force 2400 lb. per sq. in., a reduction of 8900 lb. per sq. in., or 79%. These figures bring out quite emphatically the necessity of keeping the initial stress as low as possible without endangering the rigidity of the stack.

Ordinarily, when guy wires are erected, equipment is not available for measuring the stress in the wire and the use of such equipment would hardly be practical. However, a study of the curves shown on Plates 1 and 2 will suggest a means of determining the point at which the proper stress has been induced in the wire. By referring to these plates it is seen that each curve is made up of two almost straight lines connected by a sharp curve. When the stress has been increased to the point of sharp curvature, any further deflection of the stack is due almost entirely to the elongation of the wire. That is, after this point has been reached any further increase in the stress in the wire causes but little reduction in the sag in the wire. Also, after the stress is increased up to this point, any further taking up of the wire will cause an abrupt increase in the stress in the wire which ought to be noticeable in the equipment by which the stress is induced. For ordinary cases the wire ought to be stressed up to this point but not beyond it for the best results.

APPENDIX.

Mathematical equations used in determining the curves on Plates 1 and 2.

A flexible cord or cable of uniform weight per unit length, when supported at two points and carrying only its own weight, forms a curve called a catenary. In the standard texts on analytical mechanics the catenary is treated as follows: Refer to Fig. 3. Let OR be a portion of such a cord considered as a free body. It is tangent to the horizontal at the point O. The forces acting on it are S, Ho, and its own weight. Let the weight of the cord be q per unit length and let its length be s. Its weight is qs. For algebraic convenience let the tension Ho be considered as the weight of an imaginary length c of a similar cord. Then

$Ho = q\,c$. Taking $\Sigma\, Y = O$ gives $S \frac{dy}{ds} = q.s$ and $\Sigma\, X = O$

gives $S \frac{dx}{ds} = qc$. Combining these two equations gives $c.\,dy = s.\,dx$

or $c^2\,dy^2 = s^2\,dx^2$ . . . .(1)

$dy^2 = ds^2 - dx^2$. Solving for dy and substituting in equation (1) gives

$$dx = \frac{c.\,ds}{\sqrt{s^2 + c^2}} \quad \text{or}$$

$$x = c\int_0^s \frac{ds}{\sqrt{s^2+c^2}} = c\,\log_e\left[\frac{s+\sqrt{s^2+c^2}}{c}\right] \qquad (2)$$

Put $dx^2 = ds^2 - dy^2$. Solving for dx and substituting in (1) gives

$$dy = \frac{s\;ds}{\sqrt{c^2+s^2}} = \tfrac{1}{2}\,\frac{d\,(c^2+s^2)}{\sqrt{(c^2+s^2)}} \text{ or}$$

$$y = \tfrac{1}{2}\int_0^s \frac{d\,(c^2+s^2)}{\sqrt{(c^2+s^2)}} = \tfrac{1}{2}\Big[2\,(c^2+s^2)^{\frac{1}{2}}\Big]_0^s$$

or $y = \sqrt{c^2+s^2} - c$ .... (3)

or $c = \dfrac{s^2-y^2}{2y}$ .... (4)

Transforming equation (2) in the sense in which $n = \log_e$, m may be transformed into $n_e = m$; clearing of radicals and solving for s gives $s = \tfrac{1}{2}\,c\left(e^{\frac{x}{c}} - e^{-\frac{x}{c}}\right)$ .... (5)

Again, eliminating s from (2) by substitution from (3), transforming as above, clearing of radicals, and solving for y, gives

$$y = \tfrac{1}{2}\,c\left(e^{\frac{x}{c}} - e^{-\frac{x}{c}}\right) - c \qquad (6)$$

Since the horizontal component of S must always be equal to Ho, a constant, the horizontal component of the stress in a catenary is constant. Let the tension S at any point be represented by the weight of an imaginary length of the cord equal to r. Let H and V be the horizontal and vertical components of S. Then $S = \sqrt{H^2 + V^2}$ but $H = cq$, $V = sq$ and $S = rq$. Therefore $r = \sqrt{c^2 + s^2}$.

Collecting these different equations for convenience in reference, we have the following:

$$\text{(A)} \quad x = c\,\log_e \frac{s+\sqrt{s^2+c^2}}{c}$$

$$(B)\quad y = \sqrt{s^2 + c^2} - c$$

$$(C)\quad c = \frac{s^2 - y^2}{2y}$$

$$(D)\quad s = \sqrt{2yc + y^2}$$

$$(E)\quad s = \tfrac{1}{2}c\left(e^{\frac{x}{c}} - e^{-\frac{x}{c}}\right)$$

$$(F)\quad y = \tfrac{1}{2}c\left(e^{\frac{x}{c}} + e^{-\frac{x}{c}}\right) - c$$

$$(G)\quad c = \text{a constant quantity}$$

$$(H)\quad r = \sqrt{c^2 + s^2}$$

Returning now to the problem at hand it will be seen how these equations can be applied.

While in actual construction the stress in *AC*, Fig. 2, is caused by fastening the wire to an anchor at *A*, the curve *AC* can be considered as an arc of some catenary coinciding exactly in form with it. Let *D*, Fig. 2, be the vertex of this catenary. The stress at any point of the arc of this catenary must be exactly equal to the stress at the corresponding point on the wire, as otherwise the form of the two curves would not be the same. Then consider *AC* as the arc of a catenary with vertex at *D*, and consider the stress at any point as being due to the weight of that portion of the wire between the point and *D*, imagining the support at *A* to have been removed and the wire extended to *D*. In the same manner *BC* can be considered as the corresponding arc of an equal catenary *CE*.

Consider some horizontal force, such as a wind pressure, acting upon the stack so as to move the top from *C* to *C′*. *A* and *B* will remain fixed. Following the same line of reasoning as before, *AC′* can be considered as an arc of one catenary and *BC′* of another. The length of the arc *AC′* equals the arc *AC* plus the elongation of *AC*, due to the increased tension in *AC*, and the length of the arc *BC′* equals the length of the arc *BC* minus the contraction due to the decreased tension in *BC*. These considerations fix the vertices of the catenaries *AC′* and *BC′* when *DAC*, *EBC*, *CC′* and the properties of the wire are fixed. Let *D′* and *E′* be these new vertices.

Assume an initial value of *c*. Since with a given value for *q* only one catenary can be drawn through the points *A* and *C* having a given value of *c*, the fixing of *A*, *C*, *q* and c fixes *D*. To locate *D*, apply equation (F) to the points *A* and *C* letting *x* equal the abscissa of A and $(x + a)$ the abscissa of C, and y equal the ordinate of A, and $(y + b)$ equal the ordinate of C. This gives

$$y = \tfrac{1}{2}c\left(e^{\frac{x}{c}} + e^{-\frac{x}{c}}\right) - c \text{ and}$$

$$y + b = \tfrac{1}{2}c\left(e^{\frac{x+a}{c}} + e^{-\frac{x+a}{c}}\right) - c.$$

Combining and simplifying gives

$$e^{\frac{x}{c}} - \frac{b}{c\left(e^{\frac{a}{c}} - 1\right)} = \pm\sqrt{\frac{1}{e^{\frac{a}{c}}} + \frac{b^2}{c^2\left(e^{\frac{a}{c}} - 1\right)^2}} \text{ or}$$

$$x = c \log_e \left[\left\{\frac{1}{e^{\frac{a}{c}} - 1}\right\}\left\{\frac{b}{c} \pm \sqrt{e^{\frac{a}{c}} - 2 + \frac{b^2}{c^2} + \frac{1}{e^{\frac{a}{c}}}}\right\}\right] \quad \text{(J)}$$

in which x is the horizontal distance of D to the left of A. Having assumed c, a and b, x can be determined for the point A and also for the point C. Knowing x, y can be determined from (F) and s from either (C) or (D) for the points A and C. Knowing s for A and C, the length of the arc AC can be found by subtraction.

Having located D for a given set of values for a, b and c, it now remains to find the location of D' for an assumed position of C', or the location of C' for an assumed location of D'. As the latter method is the simpler, it will be used. If C' is to be to the right of C, AD' must be greater than AD. Using equation (B) rewritten in the form $c + y = \sqrt{s^2 + c^2}$ .... (8)
This equation is true for all points on the catenary $D'AC'$ and therefore must be true for the points A and C'. Squaring equation (8) and solving for s gives $s^2 = 2cy + y^2$ .... (9)
Let s and y refer to A, and $(s + h')$ and $(y + b)$ refer to C'; in which h' is the length of the arc from A to C'.
Writing equation (9) for C' gives $(s + h')^2 = 2c\,(y + b) + (y + b)^2$...(10)
Combining (9) and (10) and solving for c gives:

$$c = \sqrt{\frac{h'^2 + 2s\ h' - b^2}{2b} - s^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Assume a value for s, that is, a location for D'. Then c can be determined from (13) since b is known and h' can be computed as follows: h' equals arc AD plus elongation in arc AD due to the increased value of the stress in AD. Arc AD = (s for C) — (s for A). Elongation $= \frac{p\,l}{E}$. In this case l = arc AD and $p = q \frac{(\text{arc. } AC)}{a} c$. For steel $E = 29{,}000{,}000$ and $q = 3.4$ lb. per ft. per sq. in. cross section of wire. For a given value of s, c can be determined approximately by inspection for use in the above formula. Knowing the elongation, h' can be calculated and substituted in equation (13) for determining c. With c and s known, x can be determined by use of equation (A) for the points A and C'. The difference between these two values of x is the horizontal distance from A to C'. Call this distance K, then the deflection of the stack is $K - a$, when the horizontal component of the stress is equal to the value of c given by equation (13) as outlined above.

As these formulae are quite complex, their use for the numerical solution of any specific case would be impracticable. The writer, therefore, undertook the solution of typical cases in order to get data from which curves could be platted for use in the solution of specific cases. The cases considered are those in which $a = 100$ ft. $b = 100$ ft. and $a = 100$ ft. $b = 50$ ft. (See Fig. 2.) From equation (J), x for the point A was determined with values of a and b as indicated above and with $c = 1000$ ft. With x known, s was determined from (E) for the points A and C. These values are for the stack in its initial position. The stack is now considered as being moved out of its original position so that C moves to C', and the relation between the deflection and the new values of c are computed as outlined above. These calculations were made for both AC' and BC' for a number of positions of C'. The results thus obtained are platted on Plates 1 and 2.

Those portions of the curves to the right of the origin are for AC and to the left for BC (Fig. 2). Consider two points, one a certain distance to the right of the origin and the other an equal distance to the left. The value of c corresponding to these points can be read from the curves. Their difference represents the righting force due to the deflection corresponding to the location of the points. In this way the lower curves on Plates 3 and 4 were derived from Plates 1 and 2. It will be noted that in the calculations from which Plates 1 and 2 were made, c was taken equal to 1000 ft. The curves can, however, be made to apply to cases in which the initial value of c is other than 1000 ft. by moving the origin along the curve until it reaches a position corresponding to the initial value of c desired. This was proven by the writer by platting and comparing curves in which the initial value of c was 300 ft., 500 ft., 1000 ft., 2000 ft., and 4000 ft. The truth of the statement is also apparent from the consideration of the fact that the relation between c and deflection is for all practical purposes the same, while the ratio between a and b varies from $a = 99.25$ ft. $b = 100$ ft. to $a = 100.300$ ft. $b = 100$ ft. which is the range found on Plate 2. It will also be noted that on Plates 1 and 2 the values of c are given in feet, while on Plates 3 and 4 the righting force is given in lb. per sq. in. cross section of wire. To reduce c in feet to force in lb. per sq. in., multiply by q the weight of a piece of wire one foot long and of one square in cross section. This for a steel wire is 3.4 lb. The upper lines on Plates 3 and 4 show the relation between the maximum stress in the wire and the deflection of the stack. The value of the stress was obtained from formulæ

$$S = qr \text{ and } r = \sqrt{s^2 + c^2}$$

DISCUSSION.

Mr. Wilson: Just a word in regard to the catenary, for the benefit of those who are not familiar with it. A flexible cord of uniform weight per unit of length, supported at the two ends and carrying only its own weight, takes a form which has been called a catenary, as illustrated in Fig 4. The lower point O, where the curve is tangent to a horizontal line, is called the vertex. Take the portion of the catenary from O to R in Fig. 5 and consider it acting as a free body. It will be acted upon by a horizontal force Ho, its own weight downward of uniform value per unit of length along the wire and a stress in the same at R which can be divided into its vertical and horizontal components. Let q be the weight per unit length of the wire, and s the length of the wire considered; the weight of the wire will be qs. For algebraic convenience, consider Ho as the weight of an imaginary length c of the same wire; that is, Ho is the weight of a cord or wire of length c. The weight per unit length being q, Ho equals qc. The point R is any point and the horizontal component of R must be equal and opposite to Ho. We can, therefore, draw the conclusion that the horizontal component of the stress in the catenary is the same at all points. With this very brief review of the laws governing the catenary, I will take up the case which we have this evening.

In Fig. 2, suppose the line OC represents the stack, which is to be vertical, and suppose we have attached to that stack at the top two wires which extend down to the vertices of the two equal catenaries, CD and CE. Suppose that these wires are up against the side of a wall and that we fasten each wire at some point, as A and B. The portion AC of the guy wire on the left is exactly the same as it was before as a portion of the catenary;

that is to say, we can consider that the guy wire AC is an arc of a catenary. If the top C moves to C', the guy wire on the left will take the form AC'; this is an arc of some other catenary which, if extended, would have a vertex at some point as D'. In the same way, the wire to the right will form a second catenary, passing through the point C' and B and down to a new orgin E'. The two original catenaries had horizontal components that were equal and opposite and therefore exerted no horizontal force upon the stack. The catenary on the right has had its horizontal component decreased; the one on the left has had its horizontal component increased. The difference between the two is the righting portion which acts upon the stack and has been called the righting force.

In the solution of the problem which we have, I have assumed certain distances out from O to A and up from O to C, and have assumed initial values of c, the horizontal stress in the wire. The first part of the problem, then, is to locate the vertex of this catenary so that with a given value of c the catenary will pass through the points A and C. We have an algebraic equation for the catenary, which gives the relation between x and y, the co-ordinates, s the length measured from the vertex, and c the imaginary length of wire whose weight is equal to the horizontal component of the stress in the wire. We know the difference between the values of the two x's, since we know the relative position of A and O; we know the difference between the values of the two y's, since we know the relation between O and C, and we have assumed a value for c. Then if we take the equation of the catenary which shows the relation between x, y and c, apply that equation to the point A, and again apply it to the point C, it will give us two equations in which the only two unknowns are x and y, and we can solve these equations and get the value of x, the horizontal distance from A to the vertex; then by adding the horizontal distance from A to C, we can get the horizontal distance from C to the vertex. In a similar manner we can get the vertical distance from C and A to D. Then having located D, we can take the equation of the catenary which shows the relation between x, s and c, and get the distance from A to D, measured along the catenary, and by applying the same equation to

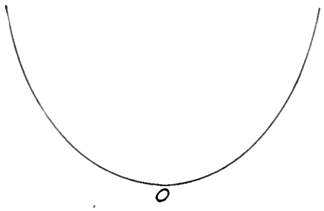


Fig 4.

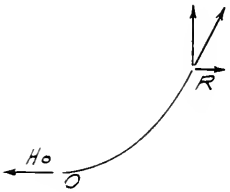


Fig 5

point C we can get the distance from C to D. The distance from C to A is the difference between those two distances.

Consider the conditions when the stack has been moved out of its vertical position from OC to OC'. We want a relation between this movement and the change in the horizontal stress in the wire. Let us examine to see what things are common between these two points. We know the vertical distance from A to C'; that is, we know the difference between the two values of y. The length of the arc AC' is equal to the arc AC plus or minus the change due to the increase or decrease in tension; so that we know the difference between the two values of s for the points A and C'. If we take the equation which shows the relations between s, y and c, and apply it to the point A and then again apply it to the point C', having first assumed a value for s, we can solve and find c, the horizontal component of the stress in the wire from C' to A. Knowing c and knowing s, we can take the equation which shows the relation between x, s and c, and solve for x, the horizontal distance from A out to the new vertex D', and likewise solve for the horizontal distance from C' to the vertex D'. Suppose we call the difference between those two values of x, K; this horizontal distance was originally equal to a, then K minus a is equal to the deflection of the stack for a value of c computed from the above equations. That is to say, we have gotten the horizontal stress in the wire on the left, due to a given deflection of the stack, and likewise we can get the horizontal stress in the wire on the right. In a similar manner we can get the horizontal stress in both cables for any other deflection, less or greater.

This gives us data for platting the curves on Plates 1 and 2, in which we have the values of c platted as ordinates, and deflection as abscissae, positive deflections being to the right and negative deflections to the left. Having this curve showing the relation between values of c and the deflection of the stack, we wish to find the righting force. To do this, we take any point on the curve which represents a given deflection to the right and a corresponding point which represents an equal deflection to the left. The ordinate of the first point represents the horizontal component of the taut wire, and the ordinate of the second represents the horizontal component of the stress in the slack wire, and their difference represents the righting force. By taking different values for the deflection, we can get the righting force for different deflections and plat the curves on Plates 3 and 4. That is the way in which those curves have actually been derived.

President Chamberlain: Mr. Wilson is to be commended for the care and the time he has taken to prepare this paper.

I desire a little information. Suppose there is no wind acting on the stack, and that the stack is exactly vertical. How would the exact stress in the cable be determined when the stack is in its normal position?

Mr. Wilson: I tried to cover that point by one of the paragraphs in the paper. It would not be practical to put in an instrument to measure the stress. It could be done, but it is not practical. Any of you who have taken hold of a rope and pulled on it know that it comes easy until you get to a point where it is almost straight; then it comes up with a sudden jerk. My idea is that it ought to be possible to feel the point where the stress increases very rapidly for a slight taking-up of the wire. While I have given a numerical value for that stress, we do not really need it. The point where the stress suddenly increases is the point to which the wire should be stretched. I lack the experience to know whether it would be possible to feel this point with a block and tackle.

Ernest McCullough, M. W. S. E.: It would be almost impossible, Mr. Wilson, unless you pulled on the rope yourself.

Mr. Wilson: Another way of determining when the proper initial stress has been obtained is by watching the sag. As we are pulling up the slack wire we reduce the sag to a point where any further taking up is due almost entirely to the elongation of the wire. At that point the taking up of the sag will practically cease,

F. B. Money, JUN. W. S. E.: It is quite certain that there is a point where we can see where the wire commences to get taut. In pulling on the line it will come evenly, and you might say well, up to a certain point; then all the slack of the wire fails to come up any more. That is the place to tie it down.

President Chamberlain: Suppose we assume an initial stress on that guy wire, and consider it simply a tension member, and resolving the forces get the horizontal component of the wind stress and make the wire strong enough with a factor of safety of four or five. Would we be in any practical error in considering the stress in that way instead of assuming it as a catenary; that is, would we be in danger?

Mr. Wilson: The answer to that question would depend upon the initial stress we put in the wire.

President Chamberlain: That is something we do not know. We have to assume that we are making it high enough to be safe.

Mr. Wilson: If we do not make the stress too great we are entirely safe, but what is neglected in that method of figuring is that while we have the tight wire resisting the wind we have the loose wire pulling with the wind. Unless the initial tension is so adjusted that the horizontal component in the loose wire is very low when the tight wire is stretched to a safe value, that loose wire is going to act with an appreciable value with the wind to break the tight wire.

J. H. Warder, Secretary: But that stress in the loose wire assisting the wind is due only to the weight of the wire.

Mr. Wilson: The stress in the taut wire is also due only to the weight of the wire.

Mr. Warder: We are supposing that it has been deflected from a vertical position and brings that tight wire in tension. Do we not have the action of wind pressure as well as the weight of the wire on the tight wire?

Mr. Wilson: As the stack is deflected, at what point is the stress in the wire due to its weight? To begin with, we have equal stresses in both wires. As the stack is deflected we say that the stress in the taut wire is due to the wind acting upon the stack and also to the anchor,-but we say that the stress in the slack wire is due simply to its weight. Just where does this transition take place?

Mr. Warder: I assume that it comes at the first deflection from the vertical line.

Mr. Wilson: The stress which is in the wire is actually due to the strain put upon the anchor, but it can likewise be considered as due to the weight of the portion of the wire that passes the stack clear down to the vertex.

President Chamberlain: It seems to me that the stress in this wire, with the stack in vertical position, is due not only to the weight of the wire, but to the initial tension in the wire, depending on how tight it is pulled on the anchor.

Mr. Wilson: The point is simply this: that with a tight wire or a slack wire the anchor will exert a stress upon the wire. It will be less on the loose wire than on the tight wire. The only way I know of to find that out is to consider the theoretical catenary extending to the vertex, but, as a matter of fact, the stress in the wire is *due* to the weight of the wire, *but is not equal to the weight of the wire.*

Mr. Warder: In the paper, two different examples are given —one where the area is 0.63 square inches and one 0.62 square inches—virtually the same thing as 7/8 inch round rod. In practice that would be using a heavier guy wire than a 7/8 inch rod.

Mr. Wilson: It must be remembered that I assumed a certain overturning force and got the wire necessary to resist that overturning force. Whether or not I use that size of wire depends upon whether our active overturning force is as great as I assumed.

S. T. Smetters, M. W. S. E.: The common practice is to increase the wire according to the span. For instance, if we guy the stack on one side 100 ft. away and on the other side 300 ft. away, we make the wire proportionate to that span. Is that correct, according to your ideas? I know the stacks stand up that way.

Mr. Wilson: Before I give a definite answer I want to look into that matter a little, but the idea does not seem to me to be logical.

Mr. Smetters: With the catenary theory I thought that the stress would be the same in proportion to the unit, although not quite in proportion.

Mr. Wilson: Assuming the stress as due entirely to the weight of the wire, if we have a wire of ½ in. cross-section, and another of 1 in. cross-section, and the two wires are exactly the same shape, the stress per unit area will be the same in the two cases.

Mr. Smetters: They would not be if one was 300 ft. away and the other was 100 ft. from the point of attachment.

Mr. Wilson: Could not the point of attachment that is further away simply include more of the catenary? These catenaries run on down to the vertex. Of course the level at which those wires were attached would have to be known.

Mr. Smetters: Yes, they would be on comparatively the same level.

Mr. Wilson: That would give us a different form of catenary on the two sides. I do not feel that my reply will be of any value until I look into the matter, which I shall be glad to do.

W. S. Marston, M. W. S. E.: One interesting point brought out by Mr. Wilson in his paper is that a slope of 1 to 1 for the wire is more economical than a slope of 1 to 2. Ordinarily we would think that the flatter the slope of the wire, the less the stress would be in it and consequently the flatter wire would be more economical. I think that is a very interesting point.

Mr. McCullough: The very fact that this long slope has been used so many years is an indication that there is a feeling that the stress is due to the weight of the cable.

John F. Hayford, M. W. S. E.: The author of the paper said that stress is due to the weight of the rope. It seems to me a little difficulty in reasoning will be avoided if we say that the stress is equal to the weight of a rope. It is not the rope used there. It is a theoretical rope which runs down to *C*, and then runs off somewhere in space. It is only in talking of that theoretical rope, which does not exist, that we can say the stress is due to the weight of the rope. The stress is due to the weight of a rope, but not to the weight of the rope that exists.

John Ensink, M. W. S. E.: It was said a while ago that those guy ropes should be stressed so far that instead of taking up segments there should be stress. The author states that—"It is evident that the less the initial stress in the wires the greater the displacement of the stack required to produce a given righting force, and also the lower the initial stress the greater the ratio of the righting force to the maximum stress in the wires."

Now what we want is that the ratio of the righting force to the stress in the wires shall be as large as possible; on the other hand, if the rope is stressed so far that there is almost no sag in it, the stress might be run up dangerously near the breaking point. So it seems to me that those ropes might be left so loose that there would be a very large sag, for according to what the author says, the ratio of the righting force to the maximum stress in the wire would then be more advantageous. From the figures given in this paper there is a deflection of those stacks of only about one inch. Now if it were six times as large—say six inches—no harm would be done. So I will ask the author if it would not be the right thing to leave those guy ropes just as slack as possible?

Wallace E. Belcher (H. M. Byllesby & Co.) (by letter): Mr. Wilson's very carefully worked out presentation of this subject forms a valuable addition to our knowledge of the relation between the stresses in guy wires and deflections of steel stacks, and as such it is of considerable interest. The conclusions given in the paper, however, seem to be open to criticism, particularly in regard to the most desirable angle of inclination for guy wires, as the author shows no proof of his argument that an angle of 45° is to be preferred to a flatter slope.

His paper also shows, when one reads between the lines, that under ordinary conditions the initial stresses in the guy wires on the leeward side of the stack have very small effect on the maximum stress on the wires. For instance, if we consider the case of a guy wire which is being tightened by two men pulling about 100 lb. each on a four-part tackle, they will put a strain on the guy of about 600 lb.; three men working the same way could put a strain on the guy of about 900 lb. As the ultimate strength of crucible cast steel rope ⅝ in. in diameter is 33,400 lb., and that of ¾ in. rope 46,000 lb., these initial tensions will have practically no effect in the determination of the size of guy wire to be used in safe practice.

The paper is rather difficult to follow on account of the use of the term *c*, which is a length used to represent a strain in pounds.

The writer wishes to make exception to the following statement in the author's paper:

> "These figures bring out quite emphatically the necessity of keeping the initial stress as low as possible without endangering the rigidity of the stack."

The practical difficulty that arises in the erection of stack guys is that the men will not put a sufficient tension on the wires. Even if the strains mentioned in the cases cited above were to be doubled they would still be of small importance. The statement of the author would be true in theory only if we were able to consider strains varying from zero to the breaking point of the wire.

The author has been led astray in his examples by the assumptions made. The maximum allowable tensile strain given as 16,000 lb. per sq. in. is good structural steel practice but has no bearing on the allowable strains for guy wires. The initial strains cited are greater than are realized in practice, as, for instance, with ¾ in. rope and the author's value, c = 2000, the initial strain would be about 2500 lb.

The first point that comes up in the design of guys for a steel stack is where to attach the sets of guys. To ascertain the correct point or points of attachment in order to bring about an equal wind load on each set of guys, and at the same time to have an equal bending moment in the stack at each attachment, which must not be exceeded at any intermediate point, is a rather complicated problem which the writer has never seen worked out for general application. The stack would be considered as a beam fixed at the base and continuous over points of support, at each set of guys, the upper part acting as a cantilever.

The author of the paper might also have considered the question of the number of guys at each point of attachment; three guys, for instance, placed at an angle of 120° will resist overturning, with no greater maximum strain on any one guy than is the case when four guys are used.

CLOSURE.

The Author: I began this problem because of my interest in it as a mathematical problem, not knowing what I was undertaking. I got what I was after—a mathematical problem—all right. It might seem that I have imposed upon the Society a mathematical paper, the practical results of which do not justify its existence, but there are some important things to be learned from this paper which should be of interest to engineers.

In talking with different engineers, I found they were all surprised that the slack wire had anything to do with the problem. As a matter of fact, it has and it is for us to know to what extent. I have proved that it does not affect the problem to an extent serious enough to be fatal, if the wires are properly erected, and in that much I have relieved other members of the engineering profession of doing it for themselves.

Another point that is now very clear to me is the danger resulting from stretching the wires too tight. With a block and tackle it is possible to almost break the wires, if they are not too large, and one may believe that by making the wires so tight, he has done a fine piece of work, whereas, as a matter of fact, it is possible to have both wires stretched up almost to the breaking point.

The most important part of the paper, in my opinion, is where I have demonstrated that if we take into account the desirability of having the stack held rigid, a slope of 1 to 1 is more economical than a slope of 1 to 2. As has been pointed out by one of the members, it is the custom to spread out the wires as flat as possible. That means simply this: that while we may not know within 100%

what the wind pressure is going to be, and we may not know within 25% to 100% what the initial stress in the wire is, so as to determine the size of the wire, we can use the material which we do use so that it will work to the greatest advantage. In the engineering profession we always meet with stresses for which we do not know just what amount of material to furnish. However, we always like to furnish the material that we do furnish so that it will do the most work possible. I think I have thrown a little light upon that subject in this paper.

Referring to Mr. Ensink's question as to whether it "would not be the right thing to leave the guy ropes as slack as possible," there are two points to consider in determining the initial stresses in guy wires. One is the righting force resulting from a given maximum stress in the wire, and the other is the rigidity of the stack. I will assume that the desirable condition is that in which we have the maximum righting force for a given sized wire and at the same time the greatest rigidity. If we do not care to reduce the deflection to a minimum, then Mr. Ensink's statement is correct. But I cannot agree with him that we can safely and deliberately allow an appreciable deflection of the stack which would result from having the wires initially loose or with considerable sag, because under the action of the gusts of wind there will be a swinging back and forth so that a puff of wind will come along and carry the stack over to its extreme position, and the wire on the taut side will have to resist not only the wind pressure but the momentum of the stack. I think it is desirable to have the stacks held as rigid as possible.

Mr. Smetters brought up a question in regard to the relative size of guy wires when the wires on the two sides of the stack do not have the same slope. If the stack has the same exposure on all sides, the two wires must be capable of exerting the same righting force. The flatter wire will have the largest ratio of horizontal component to stress in the wire, and if the slack wire did not act upon the stack the flatter of the two wires would therefore be subjected to the lesser stress. The effect of the slack wire is to modify the relation of righting force to stress in the wire. Just what this modification is will depend upon the conditions governing each particular case. However, for cases usually met with in practice, the difference in the stresses in the wires having slopes is comparatively small and the wires should be about the same size.

Referring to the discussion presented by Mr. Belcher, it is of great satisfaction to know that the paper has aroused sufficient interest to bring out a carefully prepared criticism. Each of the points brought up will be considered in order.

Mr. Belcher makes the statement that, "the author shows no proof of his argument that an angle of 45° is to be preferred to a flatter slope." My statement was that a slope of 1 to 1 is better than a slope of 1 to 2, and that statement was supported by the numerical problems preceding. In these problems two stacks were considered.

Wires having a slope of 1 to 1 were applied to one stack at a point 100 ft. from the ground and wires having a slope of 1 vertical and 2 horizontal were applied to the other stack, also at a point 100 ft. from the ground.

The initial stress in each case was that recommended. The maximum safe load to be put upon the wires was taken at 16,000 lb. per sq. in. The wire having a slope of 1 to 1 was found to require an area of 0.638 sq. in.; the maximum deflection is 0.110 ft. and the length of the wire required is 141.+ ft. The wire having a slope of 1 to 2 was found to require an area of 0.625 sq. in.; the maximum deflection is 0.104 ft. and the length of the wire required is 224 ft. Since the sectional area and the deflection of the wires is practically the same in the two cases, and as the length of the wire in the second case is much greater than that required in the first case, the conclusion was drawn that a slope of 1 to 1 is preferable to a slope of 1 vertical to 2 horizontal. This statement, however, is not general and should have been qualified. The relative merits of a slope of 1 to 1 and of 1 to 2 depend upon the initial stress in the wires and upon the maximum safe stress which is allowble, The higher the initial stress the greater the advantage of the 1 to 1 slope. The greater the maximum allowable stress the greater the advantage of the 1 to 2 slope. It was my opinion at the time the paper was written, and is yet, that the proper initial tension is that which with a slight additional taking-up of the wire there will be a large increase in the tension of the wire.

If a maximum safe working stress of 20,000 lb. per sq. in. had been used, we would have, for a slope of 1 to 1, a wire of 0.48 sq. in. cross section, 141 ft. long weighing 230 lb. and a deflection of 0.140 ft.; for a slope of 1 to 2, we would have a wire 0.461 sq. in. cross section, 224 ft. long, weighing 351 lb., and a deflection of 0.125 ft. As the wire in the second case weighs over 50% more, and the deflection is only 10% less than in the first case, it is seen that the advantage is still with the 1 to 1 slope.

The above discussion has not taken into account the more compact installation resulting from the steeper slope, which is often of great importance.

To make the paper complete, curves should have been platted for other slopes, say 2 vertical to 3 horizontal, and 3 vertical to 2 horizontal. This would have more definitely determined the slope of highest efficiency. The desirability of keeping a plant compact usually offsets any advantage in cost which might be obtained by using a slope between 1 to 1, and 1 to 2, while the rapidity with which the ratio of the stress in the wire to the horizontal component of that stress increases when the slope is made steeper than 1 to 1, is evidence, it seems to me, that a slope in the neighborhood of 1 to 1, when all practical considerations are taken into account, is the one which is the most desirable. It is my hope to go into this matter still further at some later date

In regard to the effect of the wire on the leeward side, I have pointed out that with the initial stress equal to 4900 lb. per sq. in., corresponding to an initial value of $c = 1,000$ ft., the wire on the leeward side causes a loss of possible righting force of only 17%. Until we know the value of any given force, it is as important to prove that it is small or negligible as it is to prove that it is large, and in this case at least, it is fortunate that the result of the demonstration is that this force whose determination is so complex is quite small, if not indeed negligible, for ordinary practical conditions.

In regard to the criticism of the recommended initial stress in the guy wires, I would call Mr. Belcher's attention to the fact that the wire, for which I recommended an initial stress of 4900 lb. per sq. in., corresponding to a value of $c = 1000$ ft., is attached to the stack at a point 100 ft. above the ground. Consider, for the sake of an example, a wire ⅝ in. in diameter, whose area is 0.3068 sq. in. The initial stress in the wire would then be $4900 \times 0.3068 = 1503$ lb. According to Mr. Belcher's own figures it would require only five men pulling on a four part tackle to induce this stress. Certainly no less than five men would be used to stretch a guy wire fastened at a point 100 ft. from the ground. Consider the case of a ½ in. wire guy having a slope of 1 to 1 and fastened to the stack at a point 50 ft. from the ground. The initial stress recommended is 4900 divided by $2 = 2450$ sq. in. The area of a ½ in. circle is 0.19635 sq. in. The total initial stress in the wire equals $2450 \times 0.19635 = 481$ lb., a force considerable less than that which could be produced by two men, to say nothing of what would be produced if from one to three or four bystanders were to lend a hand. It is such figures as the above—which are in strict accordance with practice—that caused the statement in my paper, "These figures bring out quite emphatically the necessity of keeping the initial stress as low as possible, without endangering the rigidity of the stack," a statement which might better be emphasized than modified. I cannot agree with Mr. Belcher in his statement that the initial value of the tension has been assumed too high.

In regard to the use of the term c, I found its use so convenient in the solution of problems, I considered it best to use it in presentation of the solution. In that I consider that I am justified

As a result of this investigation I would make the following recommendations relative to the design of guy wires: Determine the horizontal righting force which it will be necessary to apply at the point where the wires are attached to the stack. Divide this righting force by the cosine of the slope of the wire and increase the quotient by from 15% to 20% to cover the effect of the slack wire. This gives the maximum stress to which the wire is subjected, from which the required area of section can be determined by dividing it by the safe working stress for the quality of wire used. The slope of the wire should be in the neighborhood of 1 to 1. In erecting the wires they should be tightened up just to the point where any further taking up will be accompanied by a sudden increase in the stress.

ECONOMIC CONSTRUCTION OF STORAGE BINS AND TRESTLES AT CEMENT PLANTS.

W. S. Marston, M. W. S. E.

Presented Before the Bridge and Structural Section, May 10, 1911.

LOCATION PLAN.

The paper presented herewith has to deal with that part of the design of the New Cement Plant No. 6 for the Universal Portland Cement Company at Buffington, Indiana, which involves the delivery and disposal of the raw material as handled in trainload lots. The structure consists of the slag, limestone, and coal-storage bins, which form a building 31 ft. wide and 576 ft. long, and the two trestle approaches, each 1,200 ft. long, all of which make a continuous structure 2,976 ft., or a little more than half a mile, long.

Inasmuch as there are two main problems involved, the paper may properly be divided into two parts. The first part will deal with the trestle approaches, and the second part with the storage bins.

TRESTLE APPROACHES.

One of the most important problems arising in connection with the design of any trestle is the determination of that length of girder span which will reduce the total cost to a minimum. It is evident, upon even the most casual consideration of this problem, that the cost per lineal foot of trestle of the stringers will increase, and the cost per lineal foot of trestle of the steel bents and concrete foundations will decrease, as the length of span increases. There must be, therefore, some certain span length where the summation of these various items is a minimum.

In order to determine this economical length of span for the trestle at Buffington, the writer prepared tables of preliminary designs for the various items in the structure for spans varying by 2 ft. from 16 ft. up to 36 ft. Curves were platted from which the desired information could be easily obtained. These tables were, at the time, prepared somewhat roughly, but have since been very carefully revised and enlarged, and their presentation herewith will constitute the principal part of the first section of this paper.

The investigation has been made for a single track trestle with a stringer directly under the center line of each rail, and supported at regular intervals upon steel bents having two inclined posts tied together with one or more panels of cross bracing. The loading used was Cooper E-50 and the specifications were those of the American Railway Engineering and Maintenance of Way Association of 1906.

Table I shows a comparative design of stringers for spans varying by 2 ft. from 16 ft. to 36 ft., and for depths of webs varying by 6 in. from 30 in. to 66 in. It having been determined to space cross-frames about 8 ft. apart and use minimum angles of 3½ by 3 by ⅜ in. in cross-frames and lateral bracing, these details were carefully laid out for the different depths of webs and lengths of span, and the dead load thus determined per lineal foot of stringer. The dead load of track, including rails, ties, etc., was found to be 235 lb. per lin. ft. of stringer. The dead load of the stringer itself was at first approximated and correction made after the design was finally completed. The live load stresses include impact in accordance with specifications. The stresses and complete stringer designs for each different depth of web are given under columns B, C, D, etc. The total maximum live and dead load shears in *kips*, or 1,000 lb. units, are given in column No. 1. and the moments, in foot kips., in column No. 2, for each depth of web. Column No. 3 gives the section of the stringer, and column No. 4 gives the weight per lineal foot. It was found that for each different length of span, it was necessary to design stringers for only two or three depths of web in order to determine the most economical stringer. For instance, for the 16 ft. span the 30 in. stringer is most economical; as also for the 18 ft. span; for the 20 ft. span, the 42 in. stringer, and so on. For the 36 ft. span the economical stringer was found to be one with a 66 in. web. For each span the minimum weight of stringer has been underscored in the table.

In column H is given the minimum weight per lineal foot of track for each span, of two stringers and the cross-frames and bracing, and in column I is given the cost of the same per lineal foot of track.

On account of the great variation in heights of bents, tables were prepared for heights of bents varying by 5 ft., from 5 ft. to 30 ft. under the stringer.

Table II gives the design for the bents 5 ft. high for spans from 16 ft. to 36 ft. long. The vertical load given in column B was taken for the minimum stringer as previously determined in Table I. To the right of Table II is a sketch showing the type of bent used, which for the 5 ft. and 10 ft. heights has only one panel of cross bracing. The stresses given are for wind only, per lineal foot of track. In columns C, D, E, F, G, and H are given the total stress and designed section for the various members of the bent. It will be noticed that minimum sections were assumed and used for the struts and braces in all cases, the only variation in section being in the posts. In column I of Table II, is given the total weight of the bent for each span, and in columns J and K are given respectively the weights and cost per lineal foot of track.

Table III gives the design for the concrete foundations for the 5 ft. bent design of Table II. Column B gives the load on the earth including the weight of concrete and 50% of the figured impact, for spans from 16 ft. up to 36 ft. The bearing value of the earth was taken at 2 tons per sq. ft. and the required base area thus determined is given in column C. In columns D and E are given the dimensions B and A as indicated in the sketch to the right of the table. The volume of concrete in cubic yards and the total cost of one pier are given in columns F and G, and in column H is given the cost per lineal foot of track of the two piers for each bent. Similarly, in Tables IV and V are given the designs for the bent 10 ft. in height with the corresponding foundations.

Tables VIII and IX are for the bent 20 ft. in height, and are similar to those previously shown for the 5 ft. bent. To the right of Table VIII is a sketch showing the type of bent used for the 15 ft., 20 ft., 25 ft., and 30 ft. heights.

It will be noticed that the foundations for all different heights of bents are identically the same in all cases for the same length of span.

Tables VI and VII, X and XI, XII and XIII, are, respectively, for the bents 15 ft., 25 ft. and 30 ft. in height, and are similar to Tables VIII and IX.

In Table XIV, the weights per lineal foot of trestle of all the items of steel design as determined in the preceding tables have been platted, both separately and in combination, the abscissae being the spans in feet and the ordinates the weights in pounds per lineal foot of trestle. Curve 1 is for the stringers, cross-frames, and lateral bracing as determined in Table I. Curve 2 is for the bent 5 ft. in height as determined in Table II. Curve 3 is for the bent 10 ft. in height as determined in Table IV. Curves 4, 5, 6 and 7 are respectively for the bents 15 ft., 20 ft., 25 ft., and 30 ft. in height.

Curves 1-2, 1-3, 1-4, etc., are combinations of curve 1 with each one of the curves 2, 3, 4, 5, 6, and 7, and give the total weight of steel per lineal foot of trestle for each height of bent. For the 5 ft. and 10 ft. heights of bents, the minimum portions of the curves lie to the left of the diagram indicating that for these two cases the minimum weight of steel would occur at some span less than 16 ft. For the 15 ft., 20 ft., 25 ft., and 30 ft. heights of bent the minimum weight of steel is shown to lie from 22 ft. to 26 ft. length of span.

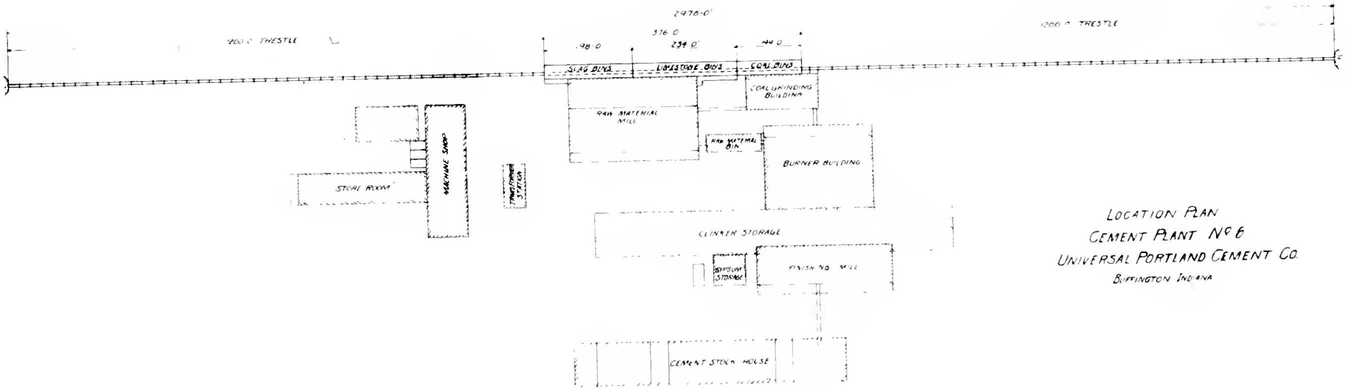
However, it is not the minimum weight of steel which determines the span length, but the minimum cost, including the cost of the foundations. Hence in Table XV the costs per lineal foot of trestle for all the items of design have been platted, both separately and in combination, the abscissae being, as before, the spans in feet, and the ordinates the cost in dollars and cents per lineal foot of trestle. Curve 1 shows the cost per lineal foot for the stringers, cross-frames, and lateral bracing. Curve 2 gives the cost per lineal foot for concrete foundations. Curve 3 shows the cost per lineal foot for the 5 ft. bent. Curves 4, 5, 6, 7 and 8 give, respectively, the costs per lineal foot for the 10 ft., 15 ft., 20 ft., 25 ft., and 30 ft. height of bents. Curve 1-2-3 is a combination of curves 1, 2 and 3 and shows the total cost per lineal foot of trestle for the 5 ft. bent. Curves 1-2-4, 1-2-5, 1-2-6, 1-2-7, and 1-2-8 are combinations of curves 1 and 2 with each one of the curves 4, 5, 6, 7 and 8, and give the total costs per lineal foot of trestle for each height of bent. It will be noticed that the minimum points for all these curves lie either at the 24 ft. or 26 ft. spans. However, as the heights of bent increase the left hand portions of the curves become higher while the right hand portions become lower, so that for the 30 ft. bent the cost for the 36 ft. span is almost the same as for the 26 ft. span. This indicates clearly that as the height of trestle increases, the minimum point shifts to the longer spans. The hump in all the curves at the 28 ft. span is caused by the addition at this point of another cross-frame and panel of bracing in the lateral bracing system.

In the computations as given, the following prices have been used: for stringers, cross-frames, and lateral bracing, $3.10 per 100 lb. erected; for bents, $3.70 per 100 lb. erected; and for concrete foundations, $6.00 per cubic yard. These prices for the steel have been compared with the records of the actual cost of this trestle erected and painted, and found to be very nearly correct.

In the computations as given, no allowance has been made for longitudinal bracing, it being assumed that, inasmuch as the tractive force per lineal foot of structure is nearly constant, the amount of longitudinal bracing required to transfer the tractive force to the foundations must also be nearly constant per lineal foot of structure for any length of span, and hence would not tend to change the point of minimum cost.

While these tables were worked out originally with the trestle at Buffington under consideration, the writer believes that in their revised and enlarged condition they should be valuable for determining the economical span for trestles of similar type and the same loading. Owing to the fluctuation in prices of material and labor it would, of course, be advisable to re-plat the cost curves in Table XV.

From a few trestles of similar type which the author has examined, the following comparisons are given in order to show what might have been saved by a careful investigation into the economical length of span. The trestle for cement plants No. 3 and No. 4 is partly an old trestle which was moved down from South Chicago when the cement plant was first started at Buffington, and was designed for conditions which fixed the length of the span at 16 ft. and for loading lighter than that of Cooper E-50. The cost of this trestle is $31.40 per lineal foot for 20 ft. height as compared with the cost of $25.93 for 26 ft. span and 20 ft. height as shown in Table XV. In other words, if this investigation had not been made, and the old trestle had been used as a model, the new trestle would have cost $13,128.00 more than as designed.



LOCATION PLAN
CEMENT PLANT Nº 6
UNIVERSAL PORTLAND CEMENT CO.
BUFFINGTON INDIANA

Another trestle about 10 ft. high under stringers and having 31 ft. span shows a cost of $32.10 per lineal foot as compared with $22.05 for 24 ft. span and 10 ft. height as shown in Table XV. In the comparisons the longitudinal bracing has not been included.

The trestles designed for the new cement plant No. 6 at Buffington consist of two single-track steel trestle approaches, each 1200 ft. long, rising from an elevation of 9.8 ft. above grade on a 2% grade for a distance of 970 ft., and then, after a vertical curve of 6500 ft. radius and 130 ft. long, running level at an elevation of 31.5 ft. above grade for a distance of 100 ft., at which point they enter the storage bin building. The loading is Cooper E-50 and the specifications those of the American Railway Engineering and Maintenance of Way Association of 1906.

Drawing B-15790 is a line diagram elevation and plan of both the east and west approaches. The trestles are shown in 600 ft. sections for convenience in exhibiting the full length of both trestles to a suitable scale. Spans of 25 ft. were used throughout except at the point where the east approach enters the coal bins. Here it was necessary to use two 32 ft. spans and two 18 ft. spans in order to match the column spacing in the adjoining coal grinding building. Expansion joints, allowing for ⅛ in. expansion or contraction for each 10 ft. in length, were placed every 100 ft. Longitudinal bracing for transferring the tractive forces to the foundation was also placed in every fourth span. This bracing consists of heavy diagonal and horizontal struts. The space below the trestle is frequently used for storing slag, limestone, and clinker, which are dumped from the cars above, hence it was considered better to use heavy compression members capable of withstanding the battering effect of falling material, rather than light tension members.

The typical stringer has a 54 by 5-16 in. web and flanges each of two angles 6 by 6 by 7-16 in. The intermediate stiffeners are 5 by 3½ by ⅜ in. angles, and the end stiffeners are of two angles 6 by 4 by ½ in. The typical bent has posts of a 10 in. by ⅜ in. web and four angles 5 by 3½ by ½ in. The top strut has two angles 5 by 3 by ⅜ in., and the middle and bottom struts have two angles 4 by 3 by ⅜ in.: the diagonal bracing is of two angles 3 by 3 by ⅜ in.

Drawing A 15790 shows the anchor bolt and foundation plans. At the top, plans are shown to a very small scale of the foundations for the east and west approaches. Section AA shows the typical concrete pier, which consists of three courses, the top one being 3 ft. square by 3 ft. 6 in. high, the middle one 5 ft. 5 in. square by 3 ft. high, and the bottom course 7 ft. 10 in. square by a height of not less than 2 ft., and as much more as may be necessary to reach good bearing. The anchor bolts are 1½ in. round and

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symmetrical loading.
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a line diagram plan
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only one is here indi-
18 ft. apart. These
main wall columns.
are the intermediate

TABLE OF STRINGER DESIGN FOR SPANS FROM 16'-0" TO 36'-0"

A	B				C				D			
	30" Web				36" Web				42" Web			
	1	2	3	4	1	2	3	4	1	2	3	4
Span	Max End Shear in Kips	Max Bend Moment in Ft Kips	Section	Wt per lin Ft of Stringer	Max End Shear in Kips	Max Bend Moment in Ft Kips	Section	Wt per lin Ft of Stringer	Max End Shear in Kips	Max Bend Moment in Ft Kips	Section	Wt. per lin. Ft of Stringer
16'-0"	LL 102.3 DL 3.0 105.3	LL 345.0 DL 12.1 357.1	Flg 4Ls 5×5×1/2" Web 30×3/8" End Stiff 4Ls 6×4×1/2 Int Stiff 2Ls 4×3×3/8"	125#	LL 102.3 DL 3.2 105.5	LL 345.0 DL 12.6 357.6	Flg 4Ls 5×5×7/16" Web 36×5/16" End Stiff 4Ls 6×4×1/2" Int Stiff 10Ls 4×3×3/8"	140#				
18'-0"	LL 111.7 DL 3.6 115.3	LL 414.8 DL 16.0 430.8	Flg. 4Ls 6×6×1/2" Web 30×7/16" End Stiff 4Ls 6×4×1/2" Int. Stiff 2Ls 4×3×3/8"	143#	LL 111.7 DL 3.6 115.3	LL 414.8 DL. 16.4 431.2	Flg. 4Ls 5×5×1/2" Web 36×3/8" End Stiff. 4Ls 6×4×1/2" Int Stiff 10Ls 4×3×3/8"	152#	LL 111.7 DL 3.6 115.3	LL 414.8 DL 16.3 431.1	Flg. 4Ls 5×5×7/16" Web 42×5/16" End Stiff. 4Ls 6×4×1/2" Int. Stiff. 10Ls 4×3×3/8"	148#
20'-0"	LL 121.1 DL 4.2 125.3	LL 484.3 DL 21.0 505.3	Flg 4Ls 6×6×5/8" Web 30×7/16" End Stiff 4Ls 6×4×1/2" Int Stiff 4Ls 4×3×3/8"	163#	LL 121.1 DL. 4.2 125.3	LL 484.3 DL 21.0 505.3	Flg 4Ls 6×6×1/2" Web 36×3/8" End Stiff 4Ls 6×4×1/2" Int Stiff 10Ls 4×3×3/8"	161#	LL 121.1 DL 4.1 125.2	LL 484.3 DL 20.6 504.9	Flg 4Ls 5×5×1/2" Web 42"×5/16" End Stiff. 4Ls 6×4×1/2" Int. Stiff. 10Ls 4×3×3/8"	153#
22'-0"	LL 127.3 DL 5.0 132.3	LL 587.6 DL 27.4 615.0	Flg 4Ls 6×6×13/16" Web 30×7/16" End Stiff 4Ls 6×6×1/2" Int Stiff 4Ls 4×3×3/8"	197#	LL 127.3 DL. 4.8 132.1	LL. 587.6 26.4 614.0	Flg. Ls 4Ls 6×6×5/8" Web 36×3/8" End Stiff 4Ls 5×6×1/2" Int. Stiff. 10Ls 4×3×3/8"	180#	LL 127.3 DL 4.7 132.0	LL 587.6 DL 25.5 613.1	Flg 4Ls 6×6×1/2" Web 42×5/16 End Stiff. 4Ls 6×6×1/2" Int. Stiff 10Ls 4×3×3/8"	165#
24'-0"												
26'-0"												
28'-0"												
30'-0"												
32'-0"												
34'-0"												
36'-0"												

A	E				F				G				H	I
	48" Web				54" Web				60" Web					
	1	2	3	4	1	2	3	4	1	2	3	4		
Span	Max End Shear in Kips.	Max Bend Moment in Ft Kips.	Section	Wt. per lin Ft of Stringer	Max End Shear in Kips	Max Bend Moment in Ft. Kips	Section	Wt per lin. Ft of Stringer	Max End Shear in Kips.	Max Bend Moment in Ft. Kips	Section	Wt per lin Ft of Stringer	Wt of Stringers and Bracing per lin Ft.	Cost of Stringers and Bracing per lin. Ft
16'-0"													289#	$8.96
18'-0"													321#	$9.95
20'-0"	LL 121.1 DL 4.1 125.2	LL 484.3 DL 20.4 504.7	Flg. 4Ls 5×5×7/16" Web 48×5/16" End Stiff 4Ls 6×4×1/2" Int. Stiff 10Ls 4×3×3/8"	157#									353#	$10.94
22'-0"	LL 127.3 DL 4.6 131.9	LL 587.6 DL 25.4 613.0	Flg. 4Ls 5×5×1/2" Web 48"×5/16" End St. ff 4Ls 6×6×1/2" Int. Stiff. 10Ls 4×3×3/8"	164	LL 127.3 DL. 4.7 132.0	LL 587.6 DL 25.6 613.2	Flg. 4Ls 5×5×7/16" Web 54×5/16 End Stiff 4Ls 6×6×1/2" Int. Stiff. 10Ls 4×3×3/8"	167#					371#	$11.50
24'-0"	LL 133.4 DL. 5.2 138.6	LL 690.0 DL 30.8 720.8	Flg. 4Ls 6×6×1/2" Web 48"×5/16 End Stiff 4Ls 6×6×1/2" Int Stiff. 10Ls 4×3×3/8"	174#	LL 133.4 DL 5.1 138.5	LL 690.0 DL 30.7 720.7	Flg. 4Ls 5×5×1/2" Web 54×5/16" End Stiff. 4Ls 6×6×1/2" Int. Stiff 10Ls 4×3×3/8"	172#	LL 133.4 DL 5.2 138.6	LL 690.0 DL 31.2 721.2	Flg. 4Ls 5×5×7/16" Web 60×5/16" End Stiff. 4Ls 6×6×1/2" Int. Stiff. 10Ls 4×3×3/8"	175#	385#	$11.94
26'-0"					LL 139.3 DL 5.7 145.0	LL 788.9 DL 37.1 826.0	Flg 4Ls 6×6×1/2" Web 54×5/16" End Stiff. 4Ls 6×6×5/8" Int Stiff. 10Ls 4×3×3/8"	185#	LL 139.3 DL 5.7 145.0	LL 788.9 DL 37.3 826.2	Flg 4Ls 5×5×1/2" Web 60×5/16" End Stiff 4Ls 6×6×5/8" Int Stiff. 10Ls 4×3×3/8"	184#	408#	$12.65
28'-0"			66" Web						LL 145.2 DL. 6.6 151.8	LL 884.5 46.0 930.5	Flg 4Ls 6×6×1/2" Web 60×5/16" End Stiff. 4Ls 6×6×5/8" Int Stiff. 14Ls 4×3×3/8"	203#	454#	$14.07
30'-0"	LL 150.9 DL. 7.1 158.0	LL 979.3 DL 53.2 1032.5	Flg 4Ls 6×6×1/2" Web 66×5/16" End Stiff. 4Ls 6×6×5/8" Int. Stiff 14Ls 5×3×3/8"	214#					LL 150.9 DL. 7.0 157.9	LL 979.3 DL 52.6 1031.9	Flg. 4Ls 6×6×7/16" Web 60×5/16" End Stiff. 4Ls 6×6×5/8" Int. Stiff 14Ls 4×3×3/8"	210#	465#	$14.42
32'-0"	LL 156.0 DL 7.7 163.7	LL 1087.1 DL 61.2 1148.3	Flg. 4Ls 6×6×7/16" Web 66×5/16" End Stiff 4Ls 6×6×5/8" Int. Stiff. 14Ls 4×3×3/8"	221#					LL 156.0 DL. 7.6 163.6	LL 1087.1 60.6 1147.7	Flg 4Ls 6×6×5/8" Web 60×5/16 End Stiff. 4Ls 6×6×5/8" Int. Stiff 14Ls 4×3×3/8"	217#	477#	$14.79
34'-0"	LL 161.0 DL 8.2 169.2	LL 1193.6 70.1 1263.7	Flg. 4Ls 6×6×5/8 Web 66×5/16" End Stiff 4Ls 6×6×5/8" Int Stiff 14Ls 5×3×3/8"	230#					LL 161.0 DL 8.2 169.2	LL 1193.6 DL. 69.4 1263.0	Flg. 4Ls 6×6×11/16" Web 60×5/16 End Stiff 4Ls 6×6×5/8" Int Stiff 14Ls 4×3×3/8"	226#	493#	$15.28
36'-0"	LL 166.5 DL 9.3 175.8	LL 1306.8 LL 83.9 1390.7	Flg. 4Ls 6×6×11/16 Web 66"×5/16 End Stiff. 4Ls 6×6×5/8" Int. Stiff 14Ls 5×3×3/8"	237					LL 166.5 DL 9.0 175.5	LL 1306.8 DL. 80.6 1387.4	Flg. 4Ls 6×6×11/16" Web 60×5/16 End Stiff 4Ls 6×6×5/8" Int. Stiff 14Ls 4×3×3/8"	243	514#	$15.93

General Notes:–
Loading:- Cooper E50.
Specifications:- American Railway Engineering & Maintenance of Way Association-1906
Track Dead Load:-Maximum taken at 235# per. lin. ft. of Stringer.
Dead Load Stresses as given in Cols. #1 & 2 include weight of Stringer.
Live Load Stresses as given in Cols #1 & 2 include impact as per Specifications- $I = S\frac{300}{L+300}$
Cost of Stringers, Crossframes, and Lateral Bracing taken at $3.10 per 100# Erected.
Stringer Weights underscored indicate economical Stringer for given Span.

TABLE No 1,
TRESTLE DESIGN.
STRINGERS.

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chors. A masonry
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design. Starting
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a typical high bent.
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caps.
design at the point
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1, and an elevation
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howing the bracing
ct of material piled

esign of the storage
form a continuous
ins are 30 ft. deep
k is a clear distance

itions: *First*—For a
spanning 31 ft. be-
ks supported on the
t the center, making
symmetrical loading.
loads taken on each
rautwine's formula

urcharge was used.

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aterial in the bins is
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en the main columns.
a line diagram plan
ins. Just below is a
nly one is here indi-
18 ft. apart. These
main wall columns.
are the intermediate

LE OF BENT

B	C	
lonBent each nger	Post	
	Stress	Sect
138.9		Web 1
6.1	+147.1	4Ls 5
45.0		
148.2		
7.1	+157.7	d
55.3		
157.4		
8.2	+167.8	d
165.6		
167.1		
9.2	+178.9	d
76.3		
176.7		
10.2	+189.7	d
86.9		
186.1		
11.5	+200.5	d
97.6		
195.5		
13.1	+211.5	d
08.6		
204.6		
14.0	+221.5	d
18.6		
215.3		Web
15.2	+234.0	4Ls 5
230.5		
225.7		
16.3	+245.0	d
42.0		
235.7		
18.6	+258.0	d
54.3		

F CONCRET

CORRESPON

B	C	
nSoil ding rete.	Base Area reqd. Bearing of 2 ton sq.ft.	
051		
388	$36.0^{0''}$	6
43.9		
12.3		
41.1	$38.4^{0''}$	6
53.4		
19.4		
43.5	$40.7^{0''}$	6
52.9		
26.8		
46.0	$43.2^{0''}$	5
72.8		
34.3		
48.4	$45.7^{0''}$	6
32.7		
91.5		
51.0	$48.1^{0''}$	7
12.5		
8.8		
4.0	$50.7^{0''}$	7
2.8		
5.9		
6.5	$53.1^{0''}$	
2.4		
4.2		
9.0	$55.8^{0''}$	
3.2		
72.3		
1.7	$58.5^{0''}$	
4.0		
0.1		
56	$61.4^{0''}$	
57		

TABLE Nº II.

TABLE OF BENTS 5-0" HIGH UNDER STRINGERS FOR SPANS FROM 16-0" TO 36-0".

A	B	C		D		E		F		G		H		I	J	K
		Post		Strut 4-5		Strut 2-3		Strut A-1		Bracing 3-4		Bracing 1-2		Total Weight of Bent.	Weight of Bent per lin ft of Trestle.	Cost of Bent per lin ft of Trestle.
Span	Load on Bent from each Stringer	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section			
16-0'	LL 138.9 DL 6.1 145.0	+1471	Web 10"×3/8" 4Ls 5×3½×3/8"	+25.8	Tie Pls 2Ls 5×3×3/8"			-24.1	Tie Pls 2Ls 4×3×3/8"			-5.8	Tie Pls 2Ls 3½×3½×3/8"	2920#	183#	$6.77
18-0'	LL 145.2 DL 7.1 155.3	+1577	do	+28.1	do			-25.9	do			-6.6	do	2920#	162#	$5.99
20-0'	LL 157.4 DL 8.2 165.6	+1678	do	+30.2	do.			-27.6	do.			-7.3	do.	2920#	146#	$5.40
22-0'	LL 167.1 DL 9.2 176.3	+1789	do	+32.5	do.			-29.4	do.			-8.0	do	2920#	133#	$4.92
24-0'	LL 176.7 DL 10.2 186.9	+1897	do	+34.8	do.			-31.2	do			-8.8	do	2920#	122#	$4.51
26-0'	LL 186.1 DL 11.5 197.6	+2005	do	+36.9	do			-32.9	do.			-9.5	do.	2920#	112#	$4.15
28-0'	LL 195.5 DL 13.1 208.6	+2115	do	+39.3	do.			-34.8	do			-10.2	do	2920#	104#	$3.85
30-0'	LL 204.6 DL 14.0 218.6	+2215	do	+41.4	do			-36.4	do.			-11.0	do.	2920#	98#	$3.63
32-0'	LL 215.3 DL 15.2 230.5	+2340	Web 10"×7/16" 4Ls 5×3½×7/16"	+43.8	do.			-38.4	do			-11.7	do	3005#	94#	$3.48
34-0'	LL 225.7 DL 16.3 242.0	+2450	do.	+46.1	do			-40.3	do			-12.4	do.	3005#	89#	$3.29
36-0'	LL 235.7 DL 18.6 254.3	+2580	do	+48.6	do			-42.4	do			-13.2	do.	3005#	84#	$3.11

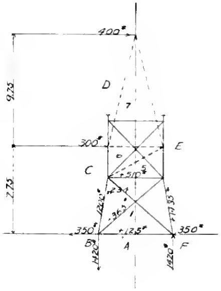
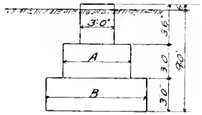


TABLE Nº III.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16-0" TO 36-0"
CORRESPONDING TO BENTS GIVEN ABOVE

A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area reqd. Bearing at 2 tons sq ft	'B'	'A'	Volume in cu yds	Cost of 1 Pier	Cost of 2 Piers per lin ft of Trestle
16-0'	LL 105.1 DL 38.8 143.9	360□'	6'2"	4'7"	7.73	$46.38	$5.80
18-0'	LL 112.3 DL 41.1 153.4	384□'	6'4"	4'8"	8.04	$48.24	$5.36
20-0'	LL 119.4 DL 43.5 162.9	407□'	6'6"	4'9"	8.37	$50.22	$5.02
22-0'	LL 126.8 DL 46.0 172.8	432□'	6'8"	4'10"	8.71	$52.26	$4.75
24-0'	LL 134.3 DL 48.4 182.7	457□'	6'10"	4'11"	9.04	$54.24	$4.52
26-0'	LL 141.5 DL 51.0 192.5	481□'	7'0"	5'0"	9.39	$56.34	$4.33
28-0'	LL 148.8 DL 54.0 202.8	507□'	7'2"	5'1"	9.75	$58.50	$4.18
30-0'	LL 155.9 DL 56.5 212.4	531□'	7'4"	5'2"	10.11	$60.66	$4.04
32-0'	LL 164.2 DL 59.0 223.2	558□'	7'6"	5'3"	10.48	$62.88	$3.93
34-0'	LL 172.3 DL 61.7 234.0	585□'	7'8"	5'4"	10.86	$65.16	$3.83
36-0'	LL 180.1 DL 65.6 245.7	614□'	7'10"	5'5"	11.24	$67.44	$3.75



TABLES Nº II AND III.
TRESTLE DESIGN.
5-0" BENTS.

General Notes :–
Cost of Steel Bents taken at $3.70 per 100# Erected.
Cost of Concrete taken at $6.00 per cu yd in place.
Impact for Foundations taken at 50% $I = \frac{S}{2}\ \frac{300}{L+300}$
Bearing value of soil taken at 2 Tons per sq ft

TABLE OF

A	B	
pan	Load on Bent from each Stringer	Stres
	LL 138.9	
6-0"	DL 6.1	+147.
	145.0	
	LL 148.2	
8-0"	DL 7.1	+157.
	155.3	
	LL 157.4	
0-0"	DL 8.2	+167.
	165.6	
	LL 167.1	
2-0"	DL 9.2	+178.
	176.3	
	LL 176.7	
4-0"	DL 10.2	+189.
	186.9	
	LL 186.1	
6-0"	DL 11.5	+200.
	197.6	
	LL 195.5	
8-0"	DL 13.1	+211.
	208.6	
	LL 204.6	
30-0"	DL 14.0	+221.
	218.6	
	LL 215.3	
32-0"	DL 15.2	+234.
	230.5	
	LL 225.7	
34-0"	DL 16.3	+245.
	242.0	
	LL 235.7	
36-0"	DL 18.6	+258.
	254.3	

TABLE OF CON
CORRE

A	B	C
Span	Load on Soil including concrete	Base
	LL 105.1	
16-0"	DL 39.2	3
	144.3	
	LL 112.3	
18-0"	DL 41.5	3
	153.8	
	LL 119.4	
20-0"	DL 43.9	4
	163.3	
	LL 126.8	
22-0"	DL 46.3	43
	173.1	
	LL 134.3	
24-0"	DL 48.6	4
	182.9	
	LL 141.5	
26-0"	DL 51.5	48
	193.0	
	LL 148.8	
28-0"	DL 54.5	50
	203.3	
	LL 155.9	
30-0"	DL 56.9	5
	212.8	
	LL 164.2	
32-0"	DL 59.6	5
	223.8	
	LL 172.3	
34-0"	DL 62.3	5
	234.6	
	LL 180.1	
36-0"	DL 66.2	6
	246.3	

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TABLE No IV.

TABLE OF BENTS 10'-0" HIGH UNDER STRINGERS FOR SPANS FROM 16'-0" TO 36'-0".

A	B	C		D		E		F		G		H		I	J	K
		Post		Strut 4-5		Strut 2-3		Strut A-1		Bracing 3-4		Bracing 1-2				
Span	Load on Bent from each Stringer	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Total Weight of Bent.	Weight of Bent per lin. ft of Trestle.	Cost of Bent per lin ft of Trestle.
16'-0"	LL 138.9 DL 6.1 145.0	+147.1	Web 10"x⅜" 4Ls 5x3½x⅜"	+25.8	Tie Pls 2Ls 5x3x⅜"			-24.1	Tie Pls 2Ls 4x3x⅜"			-7.2	Tie Pls 2Ls 3x3x⅜"	3615#	226#	$8.36
18'-0"	LL 148.2 DL 7.1 155.3	+157.7	do.	+28.1	do.			-25.9	do.			-8.1	do.	3615#	201#	$7.44
20'-0"	LL 157.4 DL 8.2 165.6	+167.8	do.	+30.2	do.			-27.6	do.			-9.0	do.	3615#	181#	$6.70
22'-0"	LL 167.1 DL 9.2 176.3	+178.9	do.	+32.5	do.			-29.4	do.			-9.9	do.	3615#	164#	$6.07
24'-0"	LL 176.7 DL 10.2 186.9	+189.7	do.	+34.8	do.			-31.2	do.			-10.8	do.	3615#	151#	$5.59
26'-0"	LL 186.1 DL 11.5 197.6	+200.5	Web 10"x[illegible] 4Ls 5x3½x[illegible]	+36.9	do.			-32.9	do.			-11.7	do.	3790#	146#	$5.40
28'-0"	LL 195.5 DL 13.1 208.6	+211.5	do.	+39.3	do.			-34.8	do.			-12.6	do.	3790#	135#	$5.00
30'-0"	LL 204.6 DL 14.0 218.6	+221.5	do.	+41.4	do.			-36.4	do.			-13.5	do.	3790#	126#	$4.66
32'-0"	LL 215.3 DL 15.2 230.5	+234.0	Web 10"x½" 4Ls 5x3½x½"	+43.8	do.			-38.4	do.			-14.4	do.	3960#	124#	$4.59
34'-0"	LL 225.7 DL 15.3 241.0	+245.0	do.	+46.1	do.			-40.3	do.			-15.3	do.	3960#	117#	$4.33
36'-0"	LL 235.7 DL 18.6 254.3	+258.0	do.	+48.6	do.			-42.4	do.			-16.3	do.	3960#	110#	$4.07

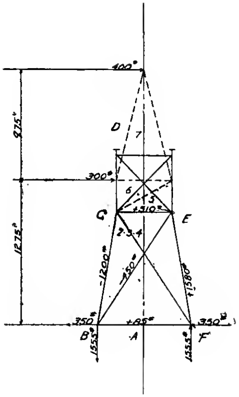
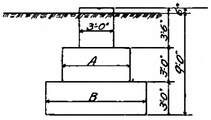


TABLE No V.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16'-0" TO 36'-0".

CORRESPONDING TO BENTS GIVEN ABOVE

A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area req'd Bearing at 2 tons sq ft	"B"	"A"	Volume in cu yds	Cost of 1 Pier	Cost of 2 Piers per lin ft of Trestle
16'-0"	LL 105.1 DL 39.2 144.3	36.1□'	6'-2"	4'-7"	7.73	$46.38	$5.80
18'-0"	LL 112.3 DL 41.5 153.8	38.4□'	6'-4"	4'-8"	8.04	$48.24	$5.36
20'-0"	LL 119.4 DL 43.9 163.3	40.8□'	6'-6"	4'-9"	8.37	$50.22	$5.02
22'-0"	LL 126.8 DL 46.3 173.1	43.3□'	6'-8"	4'-10"	8.71	$52.26	$4.75
24'-0"	LL 134.3 DL 48.6 182.9	45.7□'	6'-10"	4'-11"	9.04	$54.24	$4.52
26'-0"	LL 141.5 DL 51.5 193.0	48.2□'	7'-0"	5'-0"	9.39	$56.34	$4.33
28'-0"	LL 148.8 DL 54.5 203.3	50.8□'	7'-2"	5'-1"	9.75	$58.50	$4.18
30'-0"	LL 155.9 DL 56.9 212.8	53.2□'	7'-4"	5'-2"	10.11	$60.66	$4.04
32'-0"	LL 164.2 DL 59.6 223.8	55.9□'	7'-6"	5'-3"	10.48	$62.88	$3.93
34'-0"	LL 172.3 DL 62.3 234.6	58.6□'	7'-8"	5'-4"	10.86	$65.16	$3.83
36'-0"	LL 180.1 DL 66.2 246.3	61.3□'	7'-10"	5'-5"	11.24	$67.44	$3.75



TABLES No IV AND V,
TRESTLE DESIGN.
10'-0" BENTS.

General Notes:–
Cost of Steel Bents taken at $3.70 per 100# Erected.
Cost of Concrete taken at $6.00 per cu yd in place.
Impact for Foundations taken at 50%. $I = \frac{S}{2}\,\frac{300}{L+300}$
Bearing value of soil taken at 2 Tons per sq ft.

TABLE OF

A	B	
Span	Load on Bent from each Stringer	Stress
	LL 138.9	
16-0"	DL 6.1	+1471
	145.0	
	LL 148.2	
18-0"	DL 7.1	+1577
	155.3	
	LL 157.4	
20-0"	DL 8.2	+1678
	165.6	
	LL 167.1	
22-0"	DL 9.2	+1789
	176.3	
	LL 176.7	
24-0"	DL 10.2	+189.7
	186.9	
	LL 186.1	
26-0"	DL 11.5	+200.5
	197.6	
	LL 195.5	
28-0"	DL 13.1	+211.5
	208.6	
	LL 204.6	
30-0"	DL 14.0	+221.5
	218.6	
	LL 215.3	
32-0"	DL 15.2	+234.0
	230.5	
	LL 225.7	
34-0"	DL 16.3	+245.0
	242.0	
	LL 235.7	
36-0"	DL 18.6	+258.0
	254.3	

TABLE OF CONC
CORRES

A	B	C
Span	Load on Soil including concrete	Base A reqd Be at 2 tons
	LL 105.1	
6-0"	DL 40.0	36.
	145.1	
	LL 112.3	
8-0"	DL 42.3	38
	154.6	
	LL 119.4	
0-0"	DL 44.7	41.
	164.1	
	LL 126.8	
2-0	DL 47.1	43.
	173.9	
	LL 134.3	
-0"	DL 49.4	45
	183.7	
	LL 141.5	
-0"	DL 52.1	48
	193.6	
	LL 148.8	
-0"	DL 55.3	51.
	204.1	
	LL 155.9	
-0"	DL 57.7	53.
	213.6	
	LL 164.2	
0"	DL 60.3	56.
	224.5	
	LL 172.3	
0"	DL 63.1	58
	235.4	
	LL 180.1	
0"	DL 67.0	61.
	247.1	

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TABLE Nº VI.

TABLE OF BENTS 15'-0" HIGH UNDER STRINGERS FOR SPANS FROM 16'-0" TO 36'-0".

A	B	C		D		E		F		G		H		I	J	K
		Post		Strut 4-5		Strut 2-3		Strut A-1		Bracing 3-4		Bracing 1-2		Total Weight of Bent.	Weight of Bent per lin. ft of Trestle	Cost of Bent per lin ft. of Trestle
Span	Load on Bent from each Stringer	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section			
16'0"	LL 1389 DL 61 1450	+1471	Web 10"×⅜" 4 Ls 5×3½×⅜"	+25.8	Tie Pls 2 Ls 5×3×⅜"	+3.5	Tie Pls 2 Ls 4×3×⅜"	-24.1	Tie Pls 2 Ls 4×3×⅜"	-6.1	Tie Pls 2 Ls 3×3×⅜"	-4.3	Tie Pls 2 Ls 3×3×⅜"	5115#	320#	$11.84
18'0"	LL 1482 DL 71 1553	+1577	do	+28.1	do	+4.0	do	-25.9	do	-6.8	do	-4.9	do	5115#	284#	$10.51
20'0"	LL 1574 DL 82 1656	+1678	do	+30.2	do	+4.4	do	-27.6	do	-7.6	do	-5.4	do.	5115#	256#	$9.47
22'0"	LL 1671 DL 92 1763	+1784	do	+32.5	do.	+4.8	do	-29.4	do	-8.4	do.	-5.9	do	5115#	233#	$8.62
24'0"	LL 1767 DL 102 1869	+1897	do	+34.8	do.	+5.3	do	-31.2	do	-9.1	do	-6.5	do	5115#	213#	$7.88
26'0"	LL 1861 DL 115 1976	+2005	do	+36.9	do	+5.9	do.	-32.9	do	-9.9	do.	-7.0	do.	5115#	197#	$7.29
28'0"	LL 1955 DL 131 2086	+2115	Web 10"×7/16" 4 Ls 5×3½×7/16"	+39.3	do	+6.2	do	-34.8	do.	-10.7	do.	-7.6	do.	5375#	192#	$7.10
30'0"	LL 2046 DL 140 2186	+2215	do.	+41.4	do	+6.6	do.	-36.4	do.	-11.4	do.	-8.1	do	5375#	179#	$6.62
32'0"	LL 2153 DL 152 2305	+2340	do.	+43.8	do.	+7.1	do.	-38.4	do	-12.2	do	-8.7	do	5375#	168#	$6.22
34'0"	LL 2257 DL 163 2420	+2450	Web 10"×½" 4 Ls 5×3½×½"	+46.1	do.	+7.5	do	-40.3	do	-12.9	do.	-9.2	do.	5630#	166#	$6.14
36'0"	LL 2357 DL 186 2543	+2580	do	+48.6	do.	+7.9	do	-42.4	do.	-13.7	do	-9.7	do.	5630#	157#	$5.81

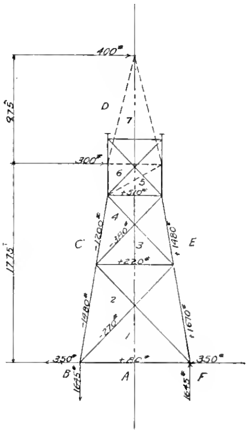
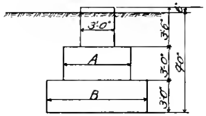


TABLE Nº VII.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16'-0" TO 36'-0".

CORRESPONDING TO BENTS GIVEN ABOVE

A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area reqd Bearing at 2 Tons sq.ft	"B"	"A"	Volume in cu yds	Cost of 1 Pier	Cost of 2 Piers per lin ft of Trestle
16'0"	LL 1051 DL 400 1451	36.3□'	6'2"	4'7"	7.73	$46.38	$5.00
18'0"	LL 1123 DL 423 1546	38.7□'	6'4"	4'8"	8.04	$48.24	$5.36
20'0"	LL 1194 DL 447 1641	41.0□'	6'6"	4'9"	8.37	$50.22	$5.02
22'0"	LL 1268 DL 471 1739	43.5□'	6'8"	4'10"	8.71	$52.26	$4.75
24'0"	LL 1343 DL 494 1837	45.9□'	6'10"	4'11"	9.04	$54.24	$4.52
26'0"	LL 1415 DL 521 1936	48.4□'	7'0"	5'0"	9.39	$56.34	$4.33
28'0"	LL 1488 DL 553 2041	51.0□'	7'2"	5'1"	9.75	$58.50	$4.18
30'0"	LL 1559 DL 577 2136	53.4□'	7'4"	5'2"	10.11	$60.66	$4.04
32'0"	LL 1642 DL 603 2245	56.1□'	7'6"	5'3"	10.48	$62.88	$3.93
34'0"	LL 1723 DL 631 2354	58.9□'	7'8"	5'4"	10.86	$65.16	$3.83
36'0"	LL 1801 DL 670 2471	61.8□'	7'10"	5'5"	11.24	$67.44	$3.75



TABLES Nº VI AND VII.

TRESTLE DESIGN.

15'-0" BENTS.

General Notes:–

Cost of Steel Bents taken at $3.70 per 100# Erected.

Cost of Concrete taken at $6.00 per cu. yd in place

Impact for Foundations taken at 50% $I = \frac{S}{2}\frac{300}{L+300}$

Bearing value of soil taken at 2 Tons per sq. ft.

TABLE OF E

A	B	
Span	Load on Bent from each Stringer	Stress
	LL 138.9	
16'-0"	DL 6.1	+147.1
	145.0	
	LL 148.2	
18'-0	DL 7.1	+157.7
	155.3	
	LL 157.4	
20'-0"	DL 8.2	+167.8
	165.6	
	LL 167.1	
22'-0"	DL 9.2	+178.9
	176.3	
	LL 176.7	
24'-0"	DL 10.2	+189.7
	186.9	
	LL 186.1	
26-0"	DL 11.5	+200.5
	197.6	
	LL 195.5	
28-0"	DL 13.1	+211.5
	208.6	
	LL 204.6	
30-0	DL 14.0	+221.5
	218.6	
	LL 215.3	
32'-0"	DL 15.2	+234.0
	230.5	
	LL 225.7	
34-0"	DL 16.3	+245.0
	242.0	
	LL 235.7	
36-0"	DL 18.6	+259.0
	254.3	

TABLE OF CONC
CORRES

A	B	C
Span	Load on Soil including concrete	Base Ar reqd-Ban at 2 tn sq
	LL 105.1	
6-0"	DL 40.4	36.4
	145.5	
	LL 112.3	
8'-0"	DL 42.7	38.8
	155.0	
	LL 119.4	
0'-0"	DL 45.1	41.1
	164.5	
	LL 126.8	
2'-0"	DL 47.5	43.6
	174.3	
	LL 134.3	
4'-0"	DL 49.9	46.1
	184.2	
	LL 141.5	
6-0"	DL 52.6	48.5
	194.1	
	LL 148.8	
8-0"	DL 55.8	51.2
	204.6	
	LL 155.9	
:0"	DL 58.3	53.6
	214.2	
	LL 164.2	
-0"	DL 60.9	56.3
	225.1	
	LL 172.3	
-0"	DL 63.8	59.
	236.1	
	LL 180.1	
-0"	DL 67.7	62.
	247.8	

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18 ft. apart. These
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TABLE Nº VIII.

TABLE OF BENTS 20'-0" HIGH UNDER STRINGERS FOR SPANS FROM 16'-0" TO 36'-0"

A	B	C		D		E		F		G		H		I	J	K
Span	Load on Bent from each Stringer	Post		Strut 4-5		Strut 2-3		Strut A-1		Bracing 3-4		Bracing 1-2		Total Weight of Bent.	Weight of Bent per lin. ft. of Trestle.	Cost of Bent per lin. ft. of Trestle.
		Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section			
16'-0"	LL 138.9 DL 6.1 145.0	+147.1	Web 10"×3/8" 4L° 5×3½×3/8"	+25.8	Tie Pls 2L° 5×3×3/8"	+3.2	Tie Pls 2L° 4×3×3/8"	-29.1	Tie Pls 2L° 4×3×3/8"	-6.7	Tie Pls 2L° 3×3×3/8"	-4.2	Tie Pls. 2L° 3×3×3/8"	5935#	371#	$13.73
18'-0"	LL 148.2 DL 7.1 155.3	+157.7	do	+28.1	do.	+3.6	do	-25.9	do.	-7.6	do.	-4.7	do	5935#	330#	$12.21
20'-0"	LL 157.4 DL 8.2 165.6	+167.8	do.	+30.2	do.	+4.0	do.	-27.6	do.	-8.4	do.	-5.2	do.	5935#	297#	$10.99
22'-0"	LL 167.1 DL 9.2 176.3	+178.9	do.	+32.5	do	+4.4	do.	-29.4	do.	-9.3	do.	-5.7	do	5935#	270#	$9.99
24'-0"	LL 176.7 DL 10.2 186.9	+189.7	Web 10"×7/16" 4L° 5×3½×7/16"	+34.8	do.	+4.8	do	-31.2	do.	-10.1	do	-6.3	do.	6275#	262#	$9.69
26'-0"	LL 186.1 DL 11.5 197.6	+200.5	do	+36.9	do.	+5.2	do	-32.9	do.	-10.9	do.	-6.8	do.	6275#	242#	$8.95
28'-0"	LL 195.5 DL 13.1 208.6	+211.5	do.	+39.3	do.	+5.6	do.	-34.8	do	-11.8	do.	-7.3	do	6275#	224#	$8.79
30'-0"	LL 204.6 DL 14.0 218.6	+221.5	Web 10"×½" 4L° 5×3½×½"	+41.4	do	+6.0	do.	-36.4	do.	-12.6	do	-7.8	do.	6615#	221#	$8.18
32'-0"	LL 215.3 DL 15.2 230.5	+234.0	do	+43.8	do.	+6.4	do	-38.4	do.	-13.4	do.	-8.3	do.	6615#	207#	$7.66
34'-0"	LL 225.7 DL 16.3 242.0	+245.0	Web 10"×9/16" 4L° 5×3½×9/16"	+46.1	do.	+6.8	do.	-40.3	do	-14.3	do.	-8.8	do.	6955#	195#	$7.22
36'-0"	LL 235.7 DL 18.6 254.3	+255.0	do	+48.6	do.	+7.2	do.	-42.4	do.	-15.1	do.	-9.4	do	6955#	189#	$6.81

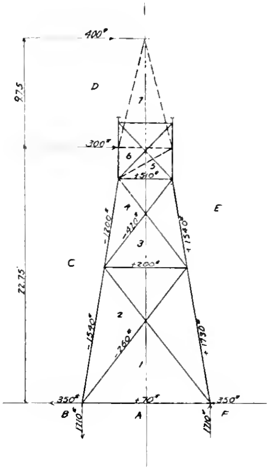
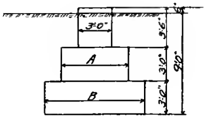


TABLE Nº IX.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16'-0" TO 36'-0".

CORRESPONDING TO BENTS GIVEN ABOVE

A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area reqd. Bearing at 2 Tons sq. ft.	"B"	"A"	Volume in cu. yds.	Cost of 1 Pier	Cost of 2 Piers per lin. ft. of Trestle.
16'-0"	LL 105.1 DL 40.4 145.5	36.4□'	6'-2"	4'-7"	7.73	$46.38	$5.80
18'-0"	LL 112.3 DL 42.7 155.0	38.8□'	6'-4"	4'-8"	8.04	$48.24	$5.36
20'-0"	LL 119.4 DL 45.1 164.5	41.1□'	6'-6"	4'-9"	8.37	$50.22	$5.02
22'-0"	LL 126.8 DL 47.5 174.3	43.6□'	6'-8"	4'-10"	8.71	$52.26	$4.75
24'-0"	LL 134.3 DL 49.9 184.2	46.1□'	6'-10"	4'-11"	9.04	$54.24	$4.52
26'-0"	LL 141.5 DL 52.6 194.1	48.5□'	7'-0"	5'-0"	9.39	$56.34	$4.33
28'-0"	LL 148.8 DL 55.8 204.6	51.2□'	7'-2"	5'-1"	9.75	$58.50	$4.18
30'-0"	LL 155.9 DL 58.3 214.2	53.6□'	7'-4"	5'-2"	10.11	$60.66	$4.04
32'-0"	LL 164.2 DL 60.9 225.1	56.3□'	7'-6"	5'-3"	10.48	$62.88	$3.93
34'-0"	LL 172.3 DL 63.8 236.1	59.0□'	7'-8"	5'-4"	10.86	$65.16	$3.83
36'-0"	LL 180.1 DL 67.7 247.8	62.0□'	7'-10"	5'-5"	11.24	$67.44	$3.75



TABLES Nº VIII AND IX,
TRESTLE DESIGN.
20'-0" BENTS

General Notes:-
Cost of Steel Bents taken at $3.70 per 100# Erected
Cost of Concrete taken at $6.00 per cu. yd. in place.
Impact for Foundations taken at 50%. $I = \frac{S}{2}\frac{300}{L+300}$
Bearing value of soil taken at 2 Tons per sq. ft.

TABLE OF BE

A	B		
		Pos	
Span	Load on Bent from each Stringer.	Stress	S
	LL 138.9		We
16'-0"	DL 6.1	+147.1	4B
	145.0		
	LL 148.2		
18'-0"	DL 7.1	+157.7	
	155.3		
	LL 157.4		W
20'-0"	DL 8.2	+167.8	4B
	165.6		
	LL 167.1		
22'-0"	DL 9.2	+178.9	
	176.3		
	LL 176.7		
24'-0"	DL 10.2	+189.7	
	186.9		
	LL 186.1		W
26'-0"	DL 11.5	+200.5	4L
	197.6		
	LL 195.5		
28'-0"	DL 13.1	+211.5	
	208.6		
	LL 204.6		W
30'-0"	DL 14.0	+221.5	4L
	218.6		
	LL 215.3		
32'-0"	DL 15.2	+234.0	
	230.5		
	LL 225.7		W
34'-0"	DL 16.3	+245.0	4L
	242.0		
	LL 235.7		
36'-0"	DL 18.6	+258.0	
	254.3		

ABLE OF CONCR
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A	B	C
pan.	Load on Soil including concrete	Base Area req'd. Bearing at 2 tons sq. ft.
	LL 105.1	
5-0"	DL 40.8	36.5□'
	145.9	
	LL 112.3	
8-0"	DL 43.1	38.9□'
	155.4	
	LL 119.4	
0-0"	DL 45.7	41.3□'
	165.1	
	LL 126.8	
2-0"	DL 48.1	43.7□'
	174.9	
	LL 134.3	
-0"	DL 50.4	46.2□'
	184.7	
	LL 141.5	
0"	DL 53.3	48.7□'
	194.8	
	LL 148.8	
0"	DL 56.4	51.3□'
	205.2	
	LL 155.9	
-0"	DL 59.0	53.7□'
	214.9	
	LL 164.2	
0"	DL 61.6	56.5□'
	225.8	
	LL 172.3	
0"	DL 64.5	59.2□'
	236.8	
	LL 180.1	
0"	DL 68.4	62.1□'
	248.5	

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are the intermediate

TABLE Nº X.

TABLE OF BENTS 25'0' HIGH UNDER STRINGERS FOR SPANS FROM 16'0" TO 36'0".

A	B	C		D		E		F		G		H		I	J	K
		Post		Strut 4-5		Strut 2-3		Strut A1		Bracing 3-4		Bracing 1-2				
Span	Load on Bent from each Stringer	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Total Weight of Bent.	Weight of Bent per lin ft of Trestle	Cost of Bent per lin ft of Trestle.
16'0"	LL 1389 DL 61 1450	+1471	Web 10"×3/8" 4Ls 5×3½×3/8"	+258	Tie Pls 2Ls 5×3×3/8"	+31	Tie Pls 2Ls 4×3×3/8"	-241	Tie Pls 2Ls 4×3×3/8"	-71	Tie Pls 2Ls 3×3×3/8"	-42	Tie Pls 2Ls 3×3×3/8"	6735#	421#	$15.58
18'0"	LL 1482 DL 71 1553	+1577	do.	+281	do.	+34	do	-259	do	-79	do	-47	do	6735#	374#	$13.84
20'0"	LL 1574 DL 82 1656	+1578	Web 10"×7/16" 4Ls 5×3½×7/16"	+302	do	+38	do.	-276	do	-88	do.	-52	do	7160#	358#	$13.25
22'0"	LL 1671 DL 92 1763	+1789	do	+325	do	+42	do.	-294	do	-97	do.	-57	do	7160#	326#	$12.06
24'0"	LL 1767 DL 102 1669	+1897	do	+348	do	+46	do.	-312	do.	-106	do.	-62	do	7160#	299#	$11.06
26'0"	LL 1861 DL 115 1976	+2005	Web 10"×½" 4Ls 5×3½×½"	+369	do.	+49	do	-329	do	-114	do.	-68	do	7585#	292#	$10.80
28'0"	LL 1955 DL 131 2086	+2115	do.	+393	do	+53	do	-348	do	-123	do.	-73	do.	7585#	271#	$10.03
30'0"	LL 2046 DL 140 2186	+2215	Web 10"×9/16" 4Ls 5×3½×9/16"	+414	do.	+5.7	do	-364	do	-13.2	do.	-78	do.	8015#	267#	$9.88
32'0"	LL 2153 DL 152 2305	+2340	do.	+438	do.	+61	do	-384	do	-141	do.	-83	do.	8015#	251#	$9.29
34'0"	LL 2257 DL 163 2420	+2450	Web 10"×5/8" 4Ls 5×3½×5/8"	-461	do	+65	do	-403	do.	-15.0	do.	-88	do	8440#	248#	$9.18
36'0"	LL 2357 DL 186 2543	+2550	do	+486	do	+69	do.	-424	do	-159	do.	-94	do.	8440#	234#	$8.66

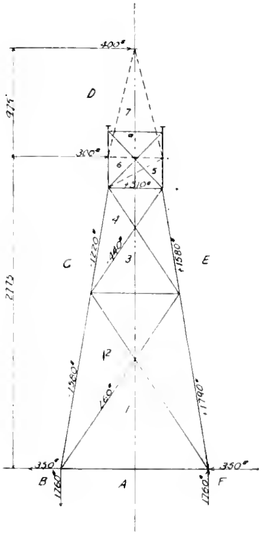


TABLE Nº XI.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16'0" TO 36'0"

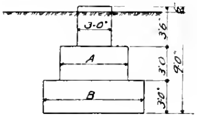
CORRESPONDING TO BENTS GIVEN ABOVE

A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area reqd. Bearing = 1½ tons sq ft	"B"	"A"	Volume in cu yds	Cost of 1 Pier	Cost of 2 Piers per lin ft of Trestle
16'0"	LL 1051 DL 408 1459	365□'	6'2"	4'7"	7.73	$46.38	$5.80
18'0"	LL 1123 DL 431 1554	389□'	6'4"	4'8"	8.04	$48.24	$5.36
20'0"	LL 1194 DL 457 1651	413□'	6'6"	4'9"	8.37	$50.22	$5.02
22'0"	LL 1268 DL 481 1749	437□'	6'8"	4'10"	8.71	$52.26	$4.75
24'0"	LL 1343 DL 504 1847	462□'	6'10"	4'11"	9.04	$54.24	$4.52
26'0"	LL 1415 DL 533 1948	487□'	7'0"	5'0"	9.39	$56.34	$4.33
28'0"	LL 1488 DL 564 2052	513□'	7'2"	5'1"	9.75	$58.50	$4.18
30'0"	LL 1559 DL 590 2149	537□'	7'4"	5'2"	10.11	$60.66	$4.04
32'0"	LL 1642 DL 616 2258	565□'	7'6"	5'3"	10.48	$62.88	$3.93
34'0"	LL 1723 DL 645 2368	592□'	7'8"	5'4"	10.86	$65.16	$3.83
36'0"	LL 1801 DL 684 2485	621□'	7'10"	5'5"	11.24	$67.44	$3.75

TABLES Nº X AND XI.

TRESTLE DESIGN.

25'-0" BENTS.



General Notes –

Cost of Steel Bents taken at $3.70 per 100# Erected

Cost of Concrete taken at $6.00 per cu yd in place

Impact for Foundations taken at 50% $I = \frac{S}{2}\frac{300}{L+300}$

Bearing value of soil taken at 2 Tons per sq. ft.

TABLE OF

A	B	
Span	Load on Bent from each Stringer	Stre
	LL 138.9	
16-0"	DL 6.1	+14
	145.0	
	LL 148.2	
18-0"	DL 7.1	+15
	155.3	
	LL 157.4	
20-0	DL 8.2	+16
	165.6	
	LL 167.1	
22-0	DL 9.2	+17
	176.3	
	LL 176.7	
24-0	DL 10.2	+18
	186.9	
	LL 186.1	
26-0	DL 11.5	+20
	197.6	
	LL 195.5	
28-0	DL 13.1	+21
	208.6	
	LL 204.6	
30-0	DL 14.0	+22
	218.6	
	LL 215.3	
32-0	DL 15.2	+23
	230.5	
	LL 225.7	
34-0	DL 16.3	+24
	242.0	
	LL 235.7	
36-0	DL 18.6	+2
	254.3	

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A	B	
Span	Load on Soil including concrete	Bo req of 2
	LL 105.1	
16-0"	DL 41.5	
	146.6	
	LL 112.3	
18-0"	DL 43.8	
	153.4	
	LL 119.4	
20-0	DL 46.5	4
	165.9	
	LL 126.8	
22-0"	DL 48.9	4
	175.7	
	LL 134.3	
24-0	DL 51.4	4
	185.7	
	LL 141.5	
26-0"	DL 54.2	4
	195.7	
	LL 148.8	
28-0"	DL 57.5	5
	206.3	
	LL 155.9	
30-0"	DL 59.9	
	215.8	
	LL 164.2	
32-0"	DL 62.7	
	226.9	
	LL 172.3	
34-0"	DL 65.3	
	237.6	
	LL 180.1	
36-0"	DL 69.3	6
	249.4	

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18 ft. apart. These
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TABLE No XII.

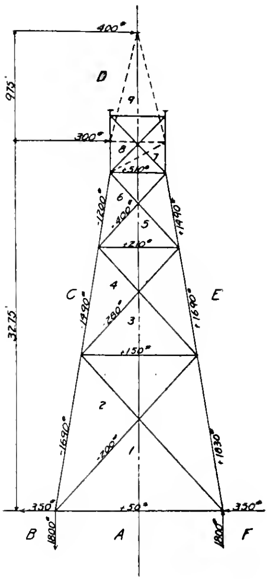
TABLE OF BENTS 5'-0" HIGH UNDER STRINGERS FOR SPANS FROM 16'-0" TO 36'-0".

A	B	C		D		E		F		G		H		I	J	K
		Post		Strut 6-7		Strut 2-3 & 4-5		Strut A-1		Bracing 3-4 & 5-6		Bracing 1-2		Total Weight of Bent.	Weight of Bent per lin. ft of Trestle.	Cost of Bent per lin. ft of Trestle
Span	Load on Bent from each Stringer	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section	Stress	Section			
16'-0"	LL 1389 DL 61 1450	+1471	Web 10"×⅜" 4Ls 5×3½×⅜"	+25.8	Tie Pls 2Ls 5×3×⅜"	+3.4	Tie Pls 2Ls 4×3×⅜"	-24.1	Tie Pls 2Ls 4×3×⅜"	-6.4	Tie Pls. 2Ls 3×3×⅜"	-3.2	Tie Pls. 2Ls 3×3×⅜"	8210#	513#	$18.98
18'-0"	LL 1482 DL 71 1553	+1577	do	+28.1	do	+3.8	do	-25.9	do.	-7.2	do	-3.6	do.	8210#	456#	$16.87
20'-0"	LL 1574 DL 82 1656	+1678	Web 10"×7/16" 4Ls 5×3½×7/16"	+30.2	do.	+4.2	do.	-27.6	do.	-8.0	do	-4.0	do	8720#	432#	$15.98
22'-0"	LL 1671 DL 92 1763	+1789	do.	+32.5	do.	+4.6	do.	-29.4	do.	-8.8	do.	-4.4	do.	8720#	396#	$14.65
24'-0"	LL 1767 DL 102 1869	+1897	Web 10"×½" 4Ls 5×3½×½"	+34.8	do.	+5.1	do.	-31.2	do.	-9.6	do.	-4.8	do.	9230#	385#	$14.25
26'-0"	LL 1861 DL 115 1976	+2005	do.	+36.9	do	+5.5	do.	-32.9	do	-10.4	do	-5.2	do.	9230#	355#	$13.14
28'-0"	LL 1955 DL 131 2086	+2115	Web 10"×9/16" 4Ls 5×3½×9/16"	+39.3	do.	+5.9	do.	-34.8	do	-11.2	do.	-5.6	do.	9745#	348#	$12.88
30'-0"	LL 2046 DL 140 2186	+2215	do	+41.4	do.	+6.3	do.	-36.4	do.	-12.0	do.	-6.0	do.	9745#	325#	$12.03
32'-0"	LL 2153 DL 152 2305	+2340	Web 10"×⅝" 4Ls 5×3½×⅝"	+43.8	do	+6.7	do.	-38.4	do.	-12.8	do.	-6.4	do.	10255#	321#	$11.88
34'-0"	LL 2257 DL 163 2420	+2458	do.	+46.1	do	+7.2	do.	-40.3	do.	-13.6	do.	-6.8	do.	10255#	302#	$11.17
36'-0"	LL 2357 DL 196 2553	+2591	do.	+48.6	do.	+7.6	do	-42.4	do.	-14.4	do.	-7.2	do.	10255#	285#	$10.55

TABLE No XIII.

TABLE OF CONCRETE FOUNDATIONS FOR SPANS FROM 16'-0" TO 36'-0".
CORRESPONDING TO BENTS GIVEN ABOVE.

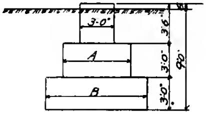
A	B	C	D	E	F	G	H
Span	Load on Soil including concrete	Base Area reqd Bearing at 2 Tons sq ft	"B"	"A"	Volume in cu yds	Cost of 1 Pier	Cost of 2 Piers per lin ft of Trestle
16'-0"	LL 105.1 DL 41.5 146.6	36.7□'	6'-2"	4'-7"	7.73	$46.38	$5.80
18'-0"	LL 112.3 DL 43.8 153.4	39.0□'	6'-4"	4'-8"	8.04	$48.24	$5.36
20'-0"	LL 119.4 DL 46.5 165.9	41.5□'	6'-6"	4'-9"	8.37	$50.22	$5.02
22'-0"	LL 126.8 DL 48.9 175.7	43.9□'	6'-8"	4'-10"	8.71	$52.26	$4.75
24'-0"	LL 134.3 DL 51.4 185.7	46.4□'	6'-10"	4'-11"	9.04	$54.24	$4.52
26'-0"	LL 141.5 DL 54.2 195.7	48.9□'	7'-0"	5'-0"	9.39	$56.34	$4.33
28'-0"	LL 148.8 DL 57.5 206.3	51.6□'	7'-2"	5'-1"	9.75	$58.50	$4.18
30'-0"	LL 155.9 DL 59.9 215.8	54.0□'	7'-4"	5'-2"	10.11	$60.66	$4.04
32'-0"	LL 164.2 DL 62.7 226.9	56.7□'	7'-6"	5'-3"	10.48	$62.88	$3.93
34'-0"	LL 172.3 DL 65.3 237.6	59.4□'	7'-8"	5'-4"	10.86	$65.16	$3.83
36'-0"	LL 180.1 DL 69.3 249.4	62.4□'	7'-10"	5'-5"	11.24	$67.44	$3.75



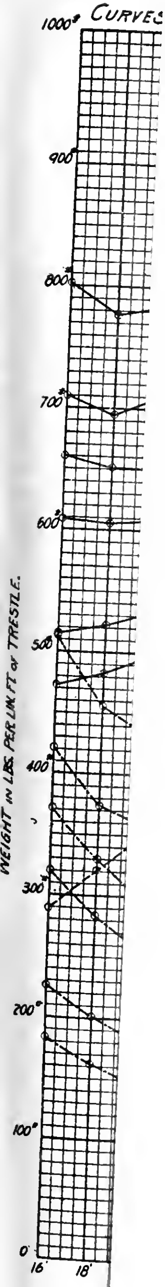
TABLES No XII AND XIII.

TRESTLE DESIGN.

30'-0" BENTS.



General Notes:—
Cost of Steel Bents taken at $3.70 per 100# Erected.
Cost of Concrete taken at $6.00 per cu yd in place.
Impact for foundations taken at 50%. $I = S\frac{300}{L+300}$
Bearing value of soil taken at 2 Tons per sq ft



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itions: *First*—For a
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en the main columns.
a line diagram plan
bins. Just below is a
only one is here indi-
18 ft. apart. These
e main wall columns.
are the intermediate

TABLE No XIV.

CURVES OF WEIGHT OF STEEL IN TRESTLE PER LIN. FT.

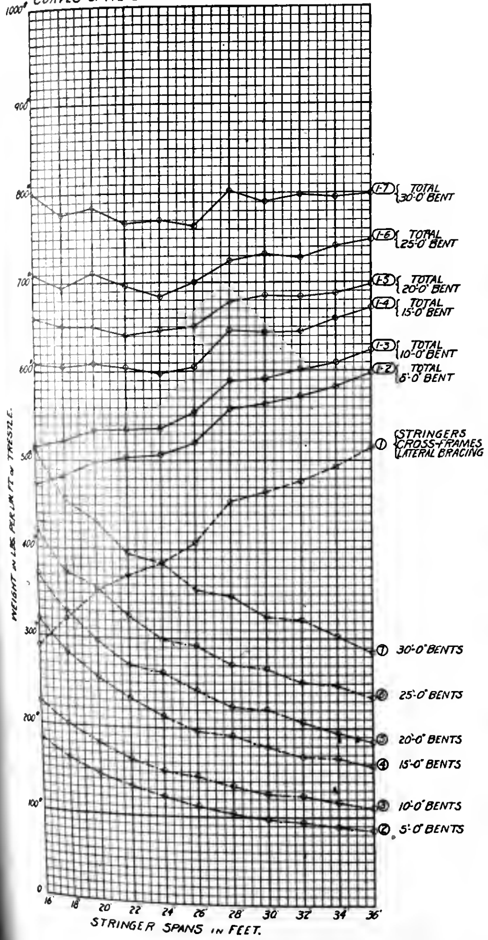
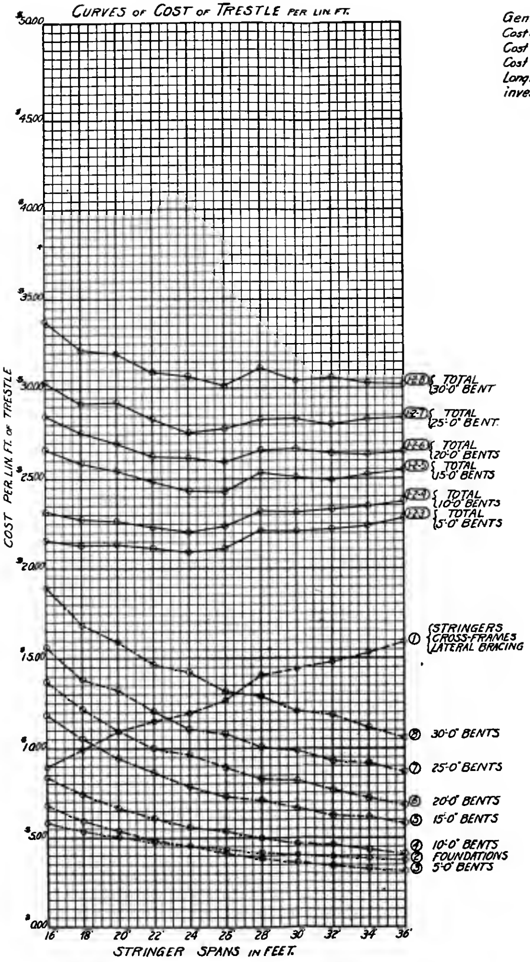


TABLE No XV.

CURVES OF COST OF TRESTLE PER LIN. FT.



General Notes:—
Cost of Stringers, etc., taken at $3.10 per 100# Erected.
Cost of Bents, etc., taken at $3.70 per 100# Erected.
Cost of Foundations taken at $6.00 per cu. yd. in place.
Longitudinal Bracing not included in this investigation.

TABLES No XIV AND XV,
TRESTLE DESIGN.

CURVES OF WEIGHT AND COST.

bent in the form of a U-bolt sufficiently long to make sure of getting the entire weight of the concrete on the anchors. A masonry plate ½ in. thick, and the size of the base plate on the bents, was carefully set and grouted in place ready to receive the steel.

Drawing C 15790, shows the typical detail design. Starting at the left at the abutment we have shown the lowest portion of the trestle in elevation and section, and also the lowest condition of longitudinal bracing. Below is shown in section a typical high bent. For expansion, slotted holes were placed in the bottom flange of the stringers where they connect to the column caps.

Drawing D 15790 shows special details of design at the point where the east trestle adjoins the coal grinding building. To the left is a plan showing bents No. 50 and No. 51, and an elevation showing the wall columns of the coal grinding building. To the right are given elevations of the same bents, showing the bracing which was put in to resist the overturning effect of material piled against the wall of the coal grinding building.

STORAGE BINS.

This section of the paper deals with the design of the storage bins for slag, limestone, and coal. These bins form a continuous structure 576 ft. long and 31 ft. wide. The bins are 30 ft. deep from base of rail to floor line, and over the track is a clear distance of 19 ft. to the roof trusses.

The structure was designed for two conditions: *First*—For a single track supported on simple floor beams spanning 31 ft. between wall columns. *Second*—For double tracks supported on the same floor beams with an additional column at the center, making a continuous girder of two equal spans and unsymmetrical loading. Cooper E-50 loading was used and full train loads taken on each track at the same time. For the bins, Trautwine's formula

$$P = \frac{WD^2}{2}\,\frac{1 - \sin.\Phi}{1 + \sin.\Phi}$$ for bin pressure without surcharge was used.

The weight of limestone was taken at 100 lb. per cu. ft. and its angle of repose 45°; slag was taken at 60 lb. per cu. ft. with an angle of repose of 45°; and coal was taken at 50 lb. per cu. ft. with an angle of repose of 35°. For the columns and all other steel encased in concrete, a safe fiber stress of 20,000 lb. per sq. in. was assumed, in order to allow for the reinforcing effect of the concrete upon the steel. The bursting effect of the material in the bins is resisted by the main columns supporting the tracks above and also by intermediate columns placed half way between the main columns.

At the top of Drawing B 15911 is shown a line diagram plan of the roof covering the slag and limestone bins. Just below is a plan of the track floor. The tracks, of which only one is here indicated, are supported on floor beams spaced 18 ft. apart. These floor beams span 31 ft. and are carried on the main wall columns. Placed midway between the main columns are the intermediate columns which are supported at the base on the foundations, and at the top frame into horizontal girders spanning between the main columns. In order to make the obstruction to dumping a minimum, no ties have been used, the rails being fastened directly to the top flange of the stringers with rail clips. A cross-frame has been placed in the center of each bay and no lateral bracing was used except in every fourth bay where heavy bracing has been used to carry the tractive forces to the side walls.

At the top of Drawing C-15911 is shown an elevation of the north wall of the slag and limestone bins looking from the inside of the building. It will be noticed that the main columns and roof trusses are spaced 18 ft. apart and the intermediate bin columns are shown extending to the track floor only. Just below in the same illustration is an elevation of the south wall, showing the openings from the bins into the raw material mill building which adjoins this side of the bins for a distance of 288 ft. The openings for the slag are less than half as large as those for limestone, being 4 ft. clear height as against 10 ft. clear height for the limestone. The width of all openings is about 16 ft.

At the left of Drawing D-15911 is a typical cross-section D-D with the part of the structure above the track floor omitted. The cross girder was designed to carry either the left hand track alone, as a simple girder spanning from wall column to wall column, or to carry the two tracks as indicated, with an additional column at the center of the structure, making a continuous girder of two equal spans. These cross girders also serve as ties taking the top reactions of the bin columns. Under these conditions it was found necessary to use a 60 by ⅜ in. web plate and flanges each of two angles 6 by 6 by ⅝ in., one cover plate 14 by ½ in., and one cover plate 14 by ⅜ in.

The maximum depth of material in the bins was assumed to be 29 ft. This gave a pressure at the floor line of 500 lbs. per lin. ft. of wall. For the main columns a 20 by ⅜ in. web was used with two angles 5 by 3½ by 7-16 in. on the tension flange and two angles 6 by 4 by ⅝ in. on the compression flange. For the intermediate columns a 20 by 5-16 in. web was used with four angles 5 by 3½ by ½ in. On the left hand side of section D-D is shown the lean-to covering the trolley used to convey material from the remote bins when the central bins are empty. Just below section D-D is shown the horizontal girder which carries the top reactions of the intermediate columns back to the main columns. Angle lacing was used in this girder rather than a web plate (which would have been cheaper), in order to allow openings for pouring the concrete wall below.

Section E-E, taken at the end of the structure, shows the type of roof truss used and also the construction of the partitions between bins.

On Drawing A-15911 are shown the details of the reinforced concrete bin walls. In designing these walls, a modulus of elasticity of 3,000,000 was taken for the steel and 3,000,000 for the concrete. A safe fibre stress of 20,000 lb. per sq. in. was taken for the steel and 750 lb. per sq. in. for the concrete. For bending moment the formula $M = \frac{WL}{10}$ was used.

At the left is shown a section through the side walls. These walls are 30 ft. high and are supported on steel columns placed 9 ft. apart. These conditions give us a wall 9 in. thick for the first 10 ft. in height, 8 in. thick for the middle 10 ft., and 7 in. thick for the top 10 ft. These thicknesses include an extra inch allowed for the excessive wear due to the limestone falling against the walls. The reinforcing consists of ½ in. square twisted bars spaced 6 in. apart for a height of 13 ft. 2 in., 8½ in. apart for 7 ft. 9½ in., and 10 in. apart for the remainder of the wall. Vertical bars ½ in. square were placed 2 ft. 3 in. apart.

At the right is a section through the partition walls. These have two lines of reinforcing bars and are of a constant thickness of 9 in. all the way up.

The reinforcing bars were secured in place by running them through holes punched in the webs of the columns.

Inasmuch as the coal bins are merely a continuation of the type of structure which has just been described for the slag and limestone bins, it will not be necessary to present the details of their construction.

DISCUSSION.

John Brunner: M. W. S. E. (Chairman): The first part of the paper which has been presented tonight deals with the investigation that was made to determine the most economical design of the railroad trestles built for the Buffington cement plant, but, as the author has pointed out, the methods used in the investigation will be applicable to other railroad trestles. It is hoped that this paper will be thoroughly discussed.

C. R. Dart, M. W. S. E.: I would like to make an inquiry similar to one that has been made before, which is, why the Universal Portland Cement Co. should not consider a concrete trestle.

I have frequently erected posts with their masonry plates, the plates being blocked up in full contact with the post bases by metal shims. After the steel has been assembled and lined the masonry plates are grouted. This method insures a proper bearing of the post on the masonry plates, and can be accomplished with little trouble if sufficient space or clearance is allowed beneath the plates.

The last time I was at Buffington I noticed a great deal of material stored outside of the bins, if I recollect right. I would ask if the storage was in bins only or the full length of the trestle.

Mr. Brunner: These trestles serve as approaches to the raw material storage bins, but are also used for dumping material which is stored under the trestles. The material stored is limestone and granulated blast-furnace slag and at times clinkers. It is important to have the members in the trestles as compact as possible so as to obtain the maximum storage space. This is the principal reason for using steel instead of reinforced concrete.

S. J. Robison: At the time the decision was made to use those masonry plates the matter was taken up with the chief director of the North Works organization and he thought they would be a good thing. We have found by experience that they are, because we can take our time to level those plates exactly with an instrument. The masons follow with a spirit level and wedge them up to the exact level; then the grout is poured and allowed to thoroughly set. In no case have the erectors found it necessary to plumb a column on any of the buildings they have erected. They have merely set up the columns, and drawn down the anchor bolts, and in every case they got it right. There has been no extra work in plumbing. I believe that in the design of the base plate some slight reduction was made in the base plate in the column proper on account of this extra masonry plate, so that the cost of the steel is not excessive; and very good results were obtained from it, I think, from the standpoint of erection cost; also from the satisfactory foundation to be had we can work roughly on concrete and then bring it up as required with grout under the plate itself.

Mr. Dart: Whether or not it is proper to do this depends upon the accuracy of the shop work on the steel and the accuracy of the men setting the plates. Not every shop will turn out material so truly faced that when lined up it will bear accurately on a true horizontal surface.

Steel bents of the size and character considered do not ordinarily require masonry plates if the base plates of the posts are made of proper thickness. The object in using masonry plates in this instance is therefore to facilitate erection, and from this standpoint their use was, without doubt, very satisfactory, and perhaps the bearings were generally accurate enough for this class of trestle. For members with large bases, carrying heavy loads, constant or frequently recurring, such procedure will not always insure sufficiently accurate bearing of posts on masonry plates or pedestals. With the ordinary errors due to the limits of accuracy in many shops, and due to the limits of accuracy of the masons, it does not seem likely that ideal results can be so obtained. There will generally be some plumbing of many of the posts, not considered sufficient in extent to warrant resetting the masonry plates, but a calculation of the stresses set up in such posts because of the deflection necessary to plumb them, may show an increase in fiber stress to a point not contemplated when the design was made.

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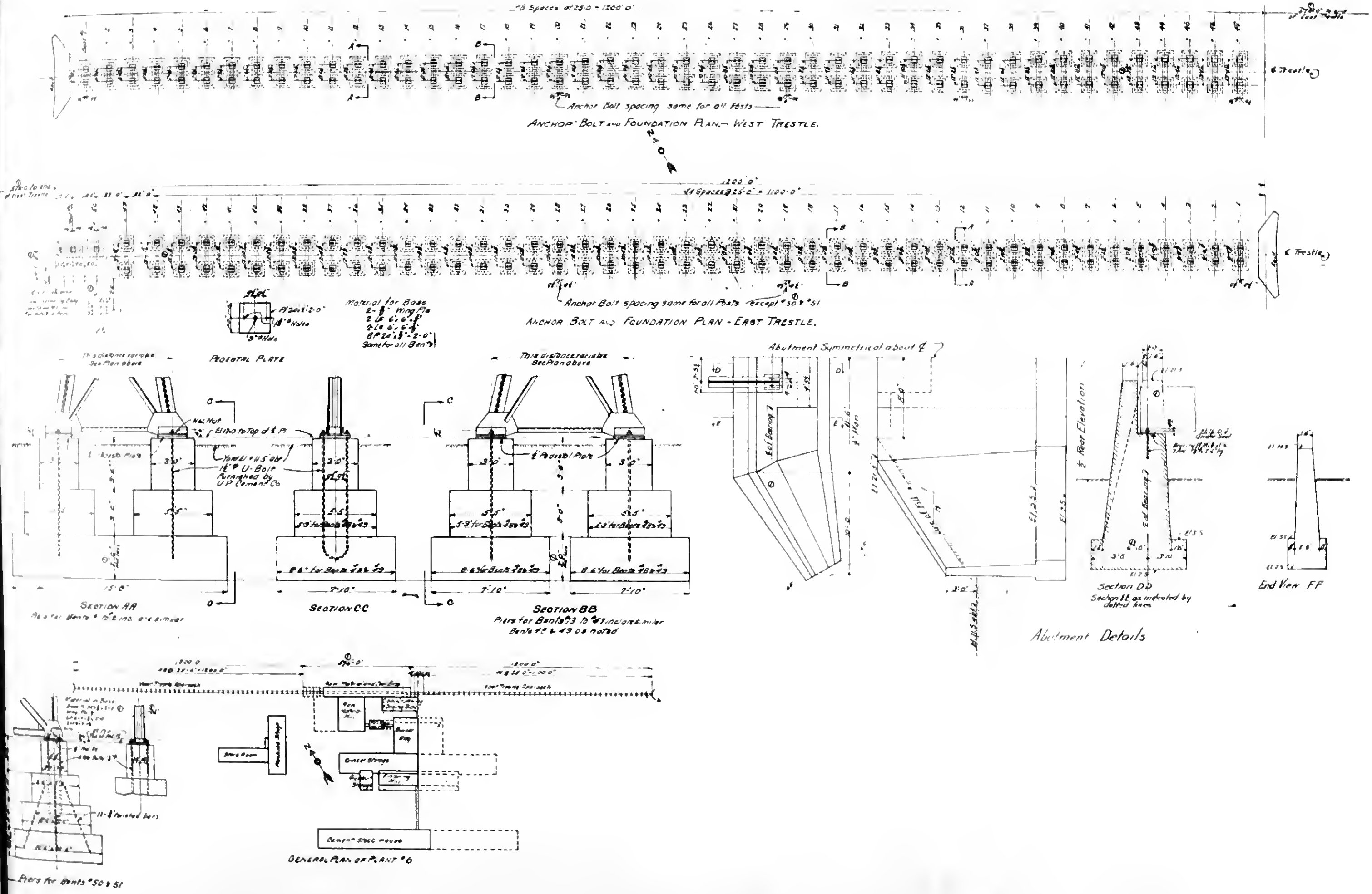
48 Spaces at 25'0" = 1200'0"
℄ Trestle
Anchor Bolt spacing same for all Posts
ANCHOR BOLT AND FOUNDATION PLAN.— WEST TRESTLE.
1200'0"
44 Spaces @ 25'0" = 1100'0"
Anchor Bolt spacing same for all Posts Except #50 & #51
ANCHOR BOLT AND FOUNDATION PLAN - EAST TRESTLE.
PEDESTAL PLATE
Material for Base
2-⅞" Wing Pls
2 ∠s 6"×6"
2 ∠s 6"×6"
BP 24"×⅞"×2'-0"
Same for all Bents
This distance variable See Plan above
½" U-Bolt Furnished by U.P. Cement Co.
½" Pedestal Plate
SECTION AA
SECTION CC
SECTION BB
Piers for Bents #3 to #47 inclusive similar. Bents #2 & 49 as noted
Abutment Symmetrical about ℄
½ Plan
½ Rear Elevation
Section DD
Section EE as indicated by dotted lines
End View FF
Abutment Details
West Trestle Approach
East Trestle Approach
Cement Storage
Cement Stock House
Machine Shop
Store Room
GENERAL PLAN OF PLANT #6
11-⅞" twisted bars
Piers for Bents #50 & 51

Drawing A 15790.

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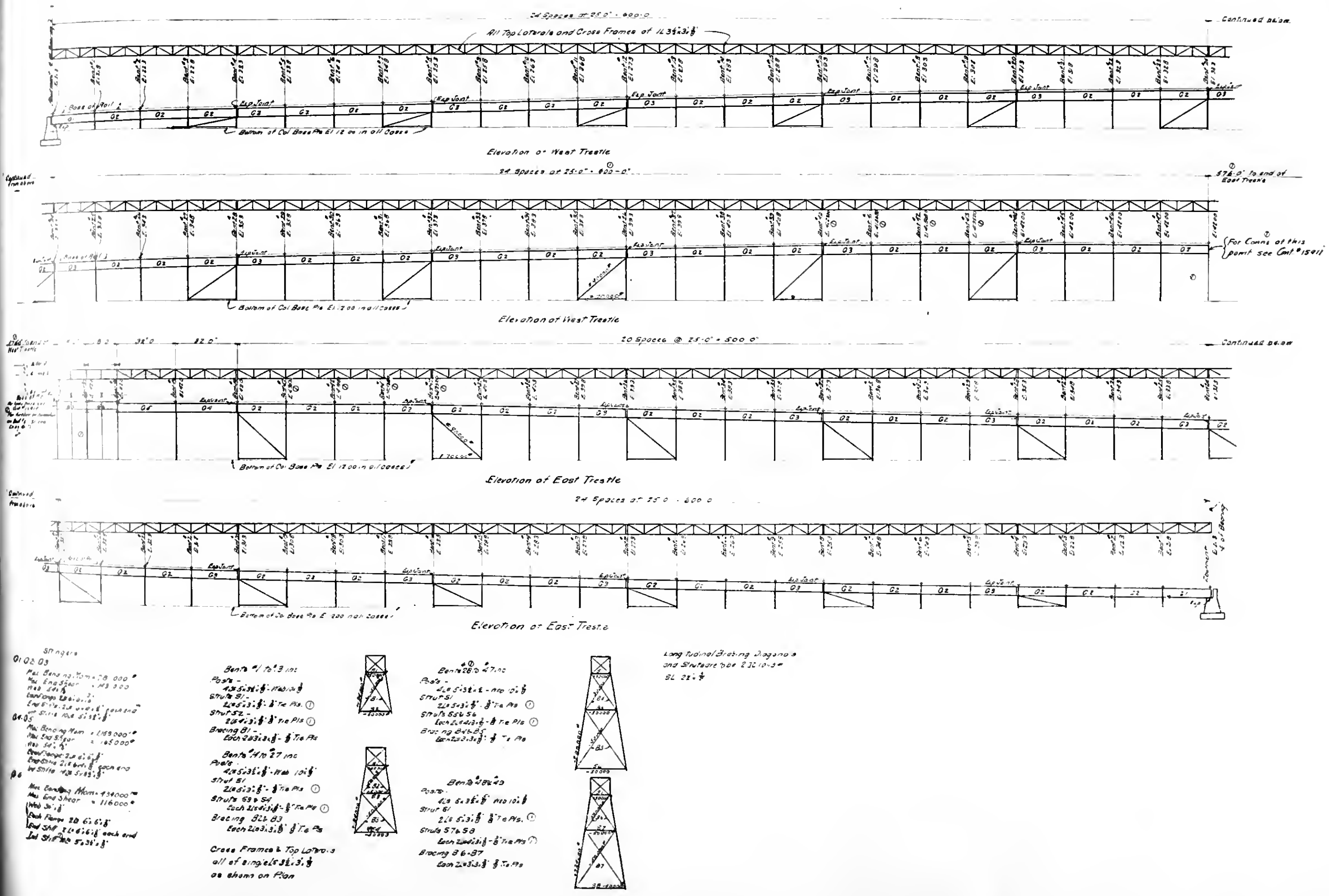
24 Spaces at 25'0" = 600'0
All Top Laterals and Cross Frames of 1L 3½x3x⅜
Continued below
Base of Rail
Exp. Joint
Bottom of Col. Base Pls. El. 12.00 in all Cases
Elevation of West Trestle
24 Spaces at 25'0" = 600'0"
576'0" to end of East Trestle
For Conns. at this point see Cont. #15911
Elevation of West Trestle
20 Spaces @ 25'0" = 500'0"
Continued below
Elevation of East Trestle
24 Spaces at 25'0 = 600'0
Elevation of East Trestle
Stringers
G1 G2 G3
Max. Bending Mom. = 78000
Max. End Shear = 113000
G4 G5
Max. Bending Mom. = 1153000
Max. End Shear = 165000
G6
Max. Bending Mom. = 434000
Max. End Shear = 116000
Bents #1 to #13 inc.
Posts -
Strut S1 -
Strut S2 -
Bracing B1 -
Bents #14 to #27 inc.
Posts -
Strut S1
Struts S3 & S4
Bracing B2 & B3
Cross Frames & Top Laterals all of single Ls 3½x3x⅜ as shown on Plan
Bents #28 to #47 inc.
Posts -
Strut S1
Struts S5 & S6
Bracing B4 & B5
Bents #48 & 49
Posts -
Strut S1
Struts S7 & S8
Bracing B6 & B7
Longitudinal Bracing Diagonals and Struts are 2 Ls 3x3x⅜

Drawing B 15790.

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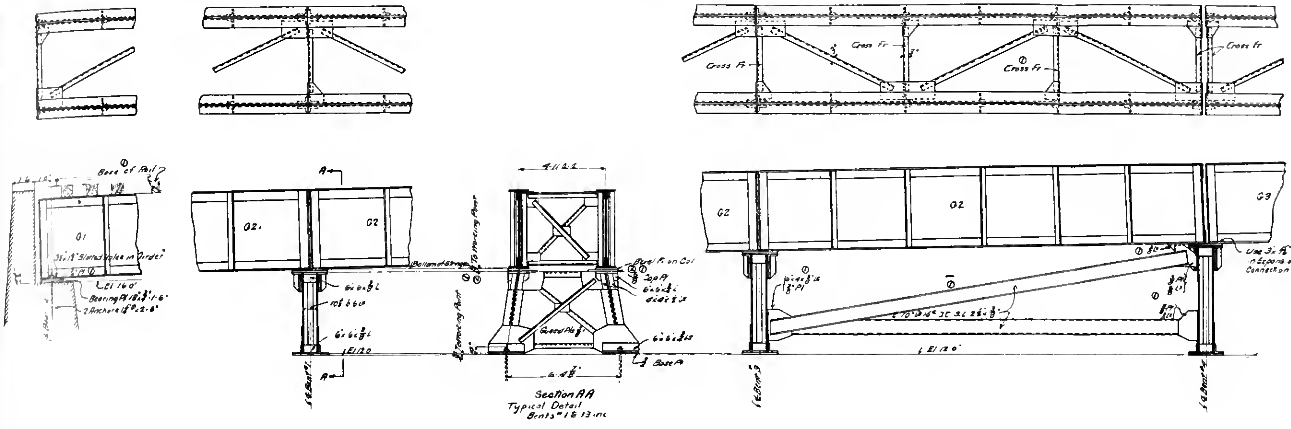
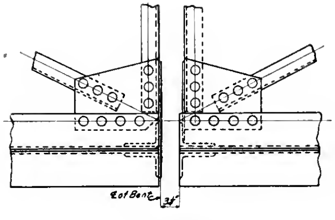
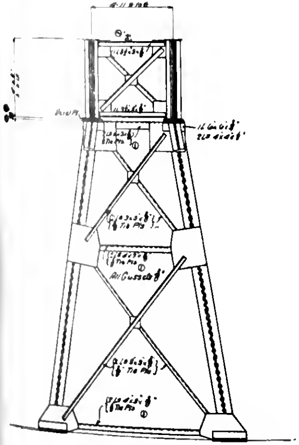


Section AA
Typical Detail
Bents #1 & 13 inc



Detail at Expansion Joint



Typical Detail
For Bents 14 to 20 inc

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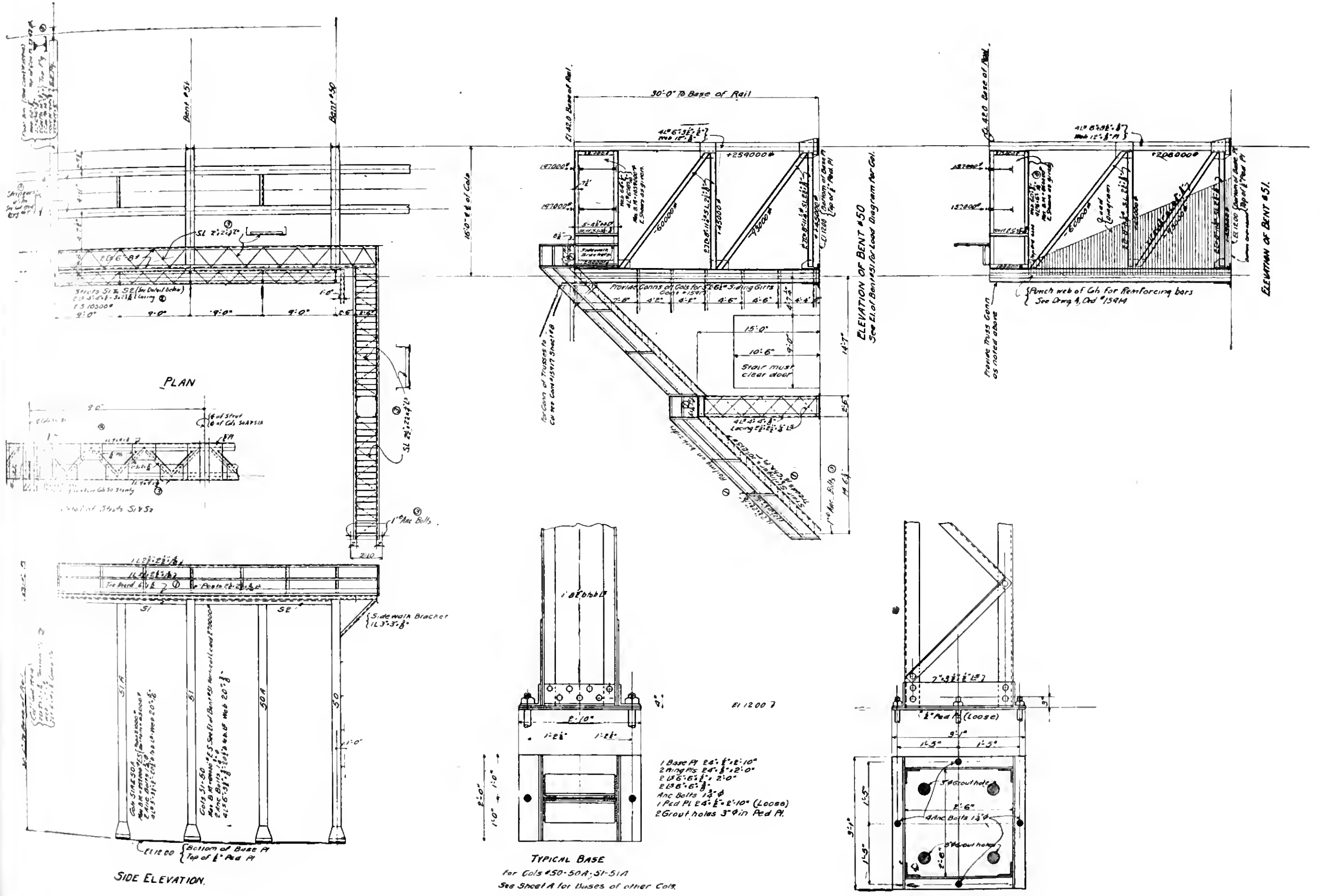

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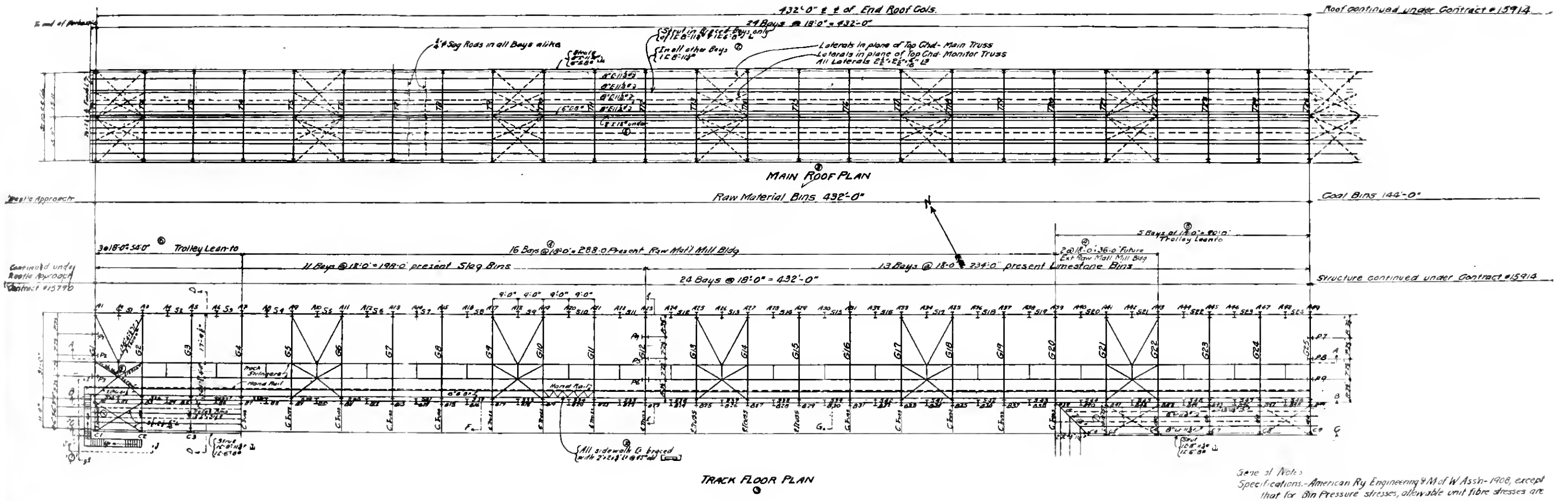
432'-0" ℄ ℄ of End Roof Cols.
Roof continued under Contract #15914
24 Bays @ 18'-0" = 432'-0"
¾" ⌀ Sag Rods in all Bays alike
Strut in Braced Bays only of 1 ⊏ 8"-11¼" & 1 ⊏ 6"-8" L
In all other Bays 1 ⊏ 8"-11¼" ②
Laterals in plane of Top Chd - Main Truss
Laterals in plane of Top Chd - Monitor Truss
All Laterals
MAIN ROOF PLAN ①
Beetle Approach
Raw Material Bins 432'-0"
Coal Bins 144'-0"
3 @ 18'-0" = 54'-0" ⑥ Trolley Lean-to
16 Bays @ 18'-0" = 288'-0" Present Raw Mat'l Mill Bldg ④
5 Bays at 18'-0" = 90'-0" Trolley Lean-to ⑤
2 @ 18'-0" = 36'-0" Future Ext Raw Mat'l Mill Bldg ④
Continued under Beetle Approach Contract #15790
11 Bays @ 18'-0" = 198'-0" present Slag Bins
13 Bays @ 18'-0" = 234'-0" present Limestone Bins
24 Bays @ 18'-0" = 432'-0"
Structure continued under Contract #15914
9'-0" 9'-0" 9'-0" 9'-0"
Track Stringers
Hand Rail
All sidewalk ⊏ braced with 2×2×¼ L's @ 45° all ③
TRACK FLOOR PLAN ③

Drawing B 15911.

General Notes

Specifications.-American Ry Engineering & M of W Ass'n - 1908, except that for Bin Pressure stresses, allowable unit fibre stresses are increased by 25%

Bin Pressures -Trautwines formula, [illegible], for Bins without surcharge, used, where w = wt per cu ft of material, D = depth of material in Bin, ϕ = angle of repose, and P = total pressure per lin ft of wall applied at ⅓D from bottom
For Limestone:- w = 100# per cu ft, ϕ = 45°, and D = 29'-0"

Roof Loads:-Dead Loads 10# for Tile 3# for purlins 5# for Trusses, Dust Load = 20#, Snow Loads = 15#, all per sq ft of horizontal projection Wind = 20# per sq ft of vertical surface and 10# per sq ft normal to Roof

Track Load - Std Cooper E 50

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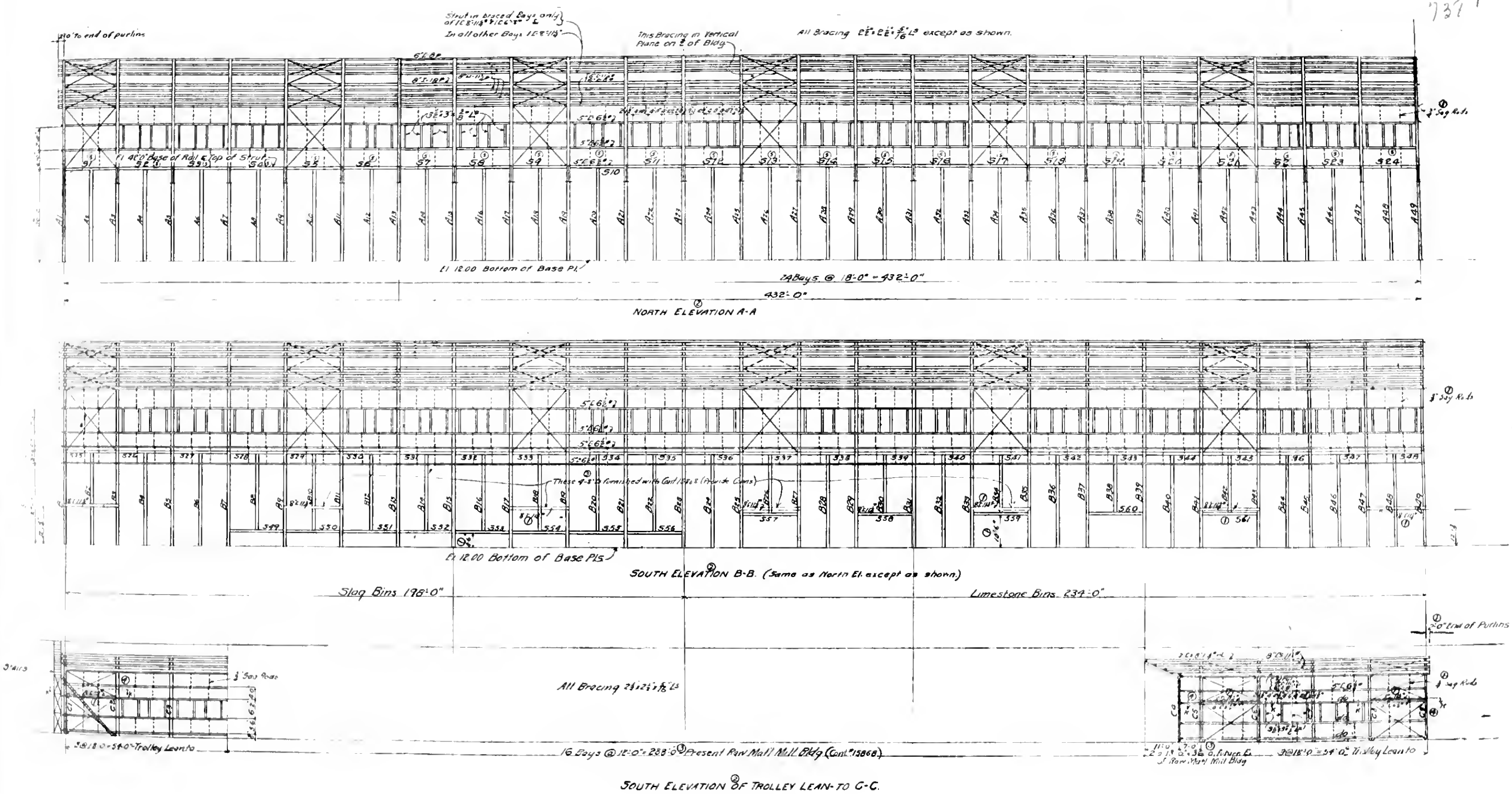
2'0" to end of purlins
Strut in braced Bays only of 1 C 8"-11¼" + 1 C 6"-8"
In all other Bays 1 C 8"-11¼"
This Bracing in Vertical Plane on ℄ of Bldg
All Bracing 2½" × 2½" × 5/16" L^s except as shown.
El 40'0" Base of Rail & Top of Strut
El 12.00 Bottom of Base Pl.
24 Bays @ 18'-0" = 432'-0"
432'-0"
NORTH ELEVATION A-A
These 4-8" [furnished with Cont. 15868 (Provide Conns)
El 12.00 Bottom of Base Pls
SOUTH ELEVATION B-B. (Same as North El. except as shown)
Slag Bins 198'-0"
Limestone Bins 234'-0"
2'0" End of Purlins
⅜" Sag Rods
All Bracing 2½ × 2½ × 5/16 L^s
3@18'0" = 54'0" Trolley Lean-to
16 Bays @ 18'-0" = 288'-0" Present Raw Mat'l Mill Bldg (Cont. 15868)
3@18'0" = 54'0" Trolley Lean to
SOUTH ELEVATION OF TROLLEY LEAN-TO C-C.

Drawing C 15911.

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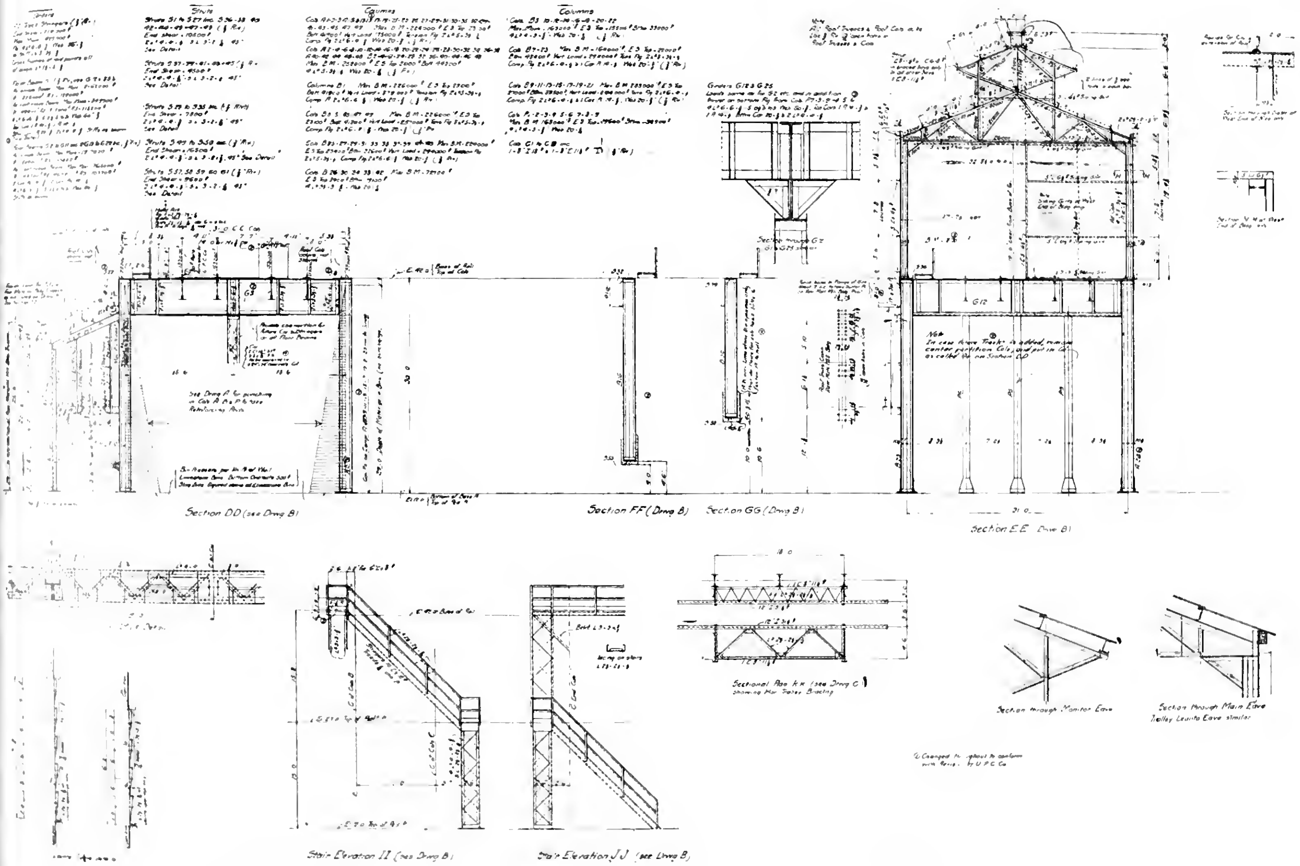

Struts
Columns
Columns
Girders G12 & G25
Section DD (see Drwg B)
Section FF (Drwg B)
Section GG (Drwg B)
Section EE Drwg B)
Sectional Plan KK (see Drwg C)
showing Mon. Truss Bracing
Section through Monitor Eave
Section through Main Eave
Trolley Leanto Eave similar
Stair Elevation II (see Drwg B)
Stair Elevation JJ (see Drwg B)
G3
G12
31 0
18 0

Drawing D 15911.

When pedestals are very heavy, however, they must be set and bedded before erection can proceed, and should be leveled with precise spirit levels. Inaccuracies of the posts in these cases are corrected only when very noticeable, and usually the unit stresses in the posts are increased to an extent in proportion to the magnitude of the errors.

Paul P. Stewart, M. W. S. E.: It will be noted that the results obtained by this investigation could not be applied to any other structure, although the method of investigation could. We used a cost figure of $6.00 per cu. yd. in our estimate of the concrete piers in place. Probably this is too cheap for the piers of other structures built where labor is higher and where perhaps cement would be more expensive. We also went down to a depth of 9 ft. below datum to get a solid bearing for the concrete footing. Under ordinary conditions it would not be necessary to go so deep. The method, therefore, is the important thing in the whole discussion, and I believe Mr. Marston has shown conclusively the large saving that can be obtained by a careful investigation of this kind. As stated herein, $13,000 was saved by using a span of 25 ft., instead of 16 ft. as had been used in similar structures for other plants.

John Ensink, M. W. S. E.: I noticed in Mr. Marston's paper that he said he had used stringers with angles 6 by 6 by 7-16 in. I do not doubt that Mr. Marston has very good authority for using that thickness of angle, but I remember that the specifications of the American Maintenance of Way Association require, in compression members, angles to be not less than one-twelfth of their width, in thickness. I think a slight difference like this will make no difference, but I know of work where angles were proposed to be used with a 6 in. leg and of ⅜ in. in thickness. I would like to ask if it is known to Mr. Marston or any of the gentlemen present, whether that is all right and whether the specifications of the American Railway Engineering and Maintenance of Way Association, are a little heavy in that respect.

Mr. Brunner: There is a difference in the application of the load on a railroad trestle located on a track where trains pass at a high rate of speed and a railroad trestle of the kind described this evening. The load on a trestle on a main line of a railroad is brought on so rapidly that the top flanges of the girders are, we may say, struck with a blow. On a trestle of the kind described this evening, the load is applied less rapidly and the action on the top flanges of the girders is not as severe. A slight variation from the requirements of the American Railway Engineering and Maintenance of Way Association's specifications may in such a case be permissible.

Mr. Marston: The difference between 7-16 in. and ½ in. is very small, and so we decided to let it go in this case.

Josiah Gibson, M. W. S. E.: There are several things that enter into consideration in the length of stringer to be used. The argument for the shorter stringer is that the moment on the stringer for uniform load decreases as the square of the span. In the specifications of the American Railway Engineering and Maintenance of Way Association, this is modified by the fact that the impact increases slightly as the span grows longer and also the equivalent uniform load on the stringer decreases. Advantage is also gained by increasing the depth of the stringer. On Curve No. 1, Table XIV, the increase in weight per foot of stringers is shown by a line which is almost straight, increasing about as the length of the stringer instead of as the square of the stringer.

There is also a point in the design of the bents. To be economical, the column must have the relation of the length of column to the radius of gyration within certain limits. In short spans the column load is small, making the area of the columns small, and as we must not use too thin metal, the radius of gyration will be low. As the span grows longer we can approach more nearly the desired limits. Thus, as far as the bents are concerned, the higher the structure the longer the desired span would be.

Wilbur M. Wilson, M. W. S. E.: I wish to emphasize the point brought out by Mr. Stewart. The lesson to learn, it seems to me, is not the particular way in which a trestle has been designed or the particular way in which bins have been designed, but it is the importance to the engineer of investigating all of the different designs of any structure to see which is the cheapest. The saving pointed out in the paper would cover a great deal more engineering expense than has been put upon the whole structure, and there are very few structures which we are called upon to design, in which there is not a similar although usually not so large an opportunity to effect a saving by scientific investigation of the different methods in which the design may be made.

J. H. Warder, (Secretary): In this grade trestle, was every successive pair of posts in the grade of a varying length or was the varying height to suit the grade made up in the foundation?

Mr. Marston: The tops of the foundations are all at the same elevation; the difference of height occurs in the height of the steel bents. Every succeeding pair of steel bents varies from its preceding one and succeeding one. That variation for 25 ft. on a 2% grade amounts to 6 inches.

M. B. Wishard: I am more familiar with the details of the work than the design, but I understand that the cement people are much pleased with the details and the way the work went together. In fact, I looked over the whole cement plant recently and it is certainly a fine piece of work to look at from the outside; it went together very well, too.

The question of masonry plates I think has been well settled, by Mr. Robison. It seems that when the steel work is in place, if the masonry plates are already set it is easy to put the steel work on top and have nothing to level up. The erection problem is facilitated when everything is ready, as in this case, because the work can go right along. I think it is a great advantage to have the masonry plates set first.

Mr. Stewart: I would inquire from Mr. Dart, or any of our railroad friends who happen to be here, whether or not investigations of this kind are usually made on long railroad structures.

Mr. Dart: I have not been connected with railroad work for many years, but one would naturally suppose that with a trestle of any size such investigations would be made.

S. T. Smetters, M. W. S. E.: Investigations were made on various types of structures for the South Side Elevated Railroad. Built-up posts of plates and angles, channels and I-beams, and channels laced, were considered. Length of span and type of girders for stringers were studied. The solid web girder, double intersection latticed web, gusset plate and angle web, and the Warren truss web made of flat bars, were designed and estimates made on each type. Also several designs were developed for expansion bearings or joints.

Quite often there is no time allowed for investigation. The shop needs the work (that was true when I was at the North Works, Illinois Steel Company), and the details must be made very quickly. The type of trestle that was used at Joliet has been in service for many years without care of any sort and seems to stand abuse and ill use very well. The solid type post with four angles riveted solidly together, with large gusset plates connecting their tops, forming the cross girder to which the stringers are connected, was used. The posts had a batter of one to six with no cross bracing, and were anchored securely to their concrete foundations.

Mr. Marston: The investigation within the limits we have taken leads to an understanding of the fact that we have merely scratched the surface of this subject. I would like very much to see a similar investigation carried out between wider limits; perhaps not so much for shorter spans as for longer spans and higher trestles. The indication, as shown by the curves as far as we have worked them out, seems to be that as the height of the trestle increases the economic span length shifts to the longer spans. It might be possible between wider limits to work out some arbitrary formulae for the relation between the length of the economical span and the height of the trestle.

NOTES ON A TELEPHONE SYSTEM RECENTLY BUILT IN SAN FRANCISCO AND ITS NEIGHBORHOOD.

Samuel G. McMeen, m. w. s. e.

Presented at a Joint Meeting of the Electrical Section W. S. E. and the Chicago Section A. I. E. E., May 24, 1911.

The system here described serves the cities of San Francisco, Oakland and Berkeley, California. The population of those cities is about 609,000, of which 417,000 are in San Francisco. The cities lie on the east and west shores of San Francisco Bay. Their relation is such that a considerable fraction of the population of Oakland and Berkeley goes daily to and from places of business in San Francisco, and in this sense the former cities are suburban to the latter. In other senses they are not suburban; they contain industries and institutions tending to give them independent characters.

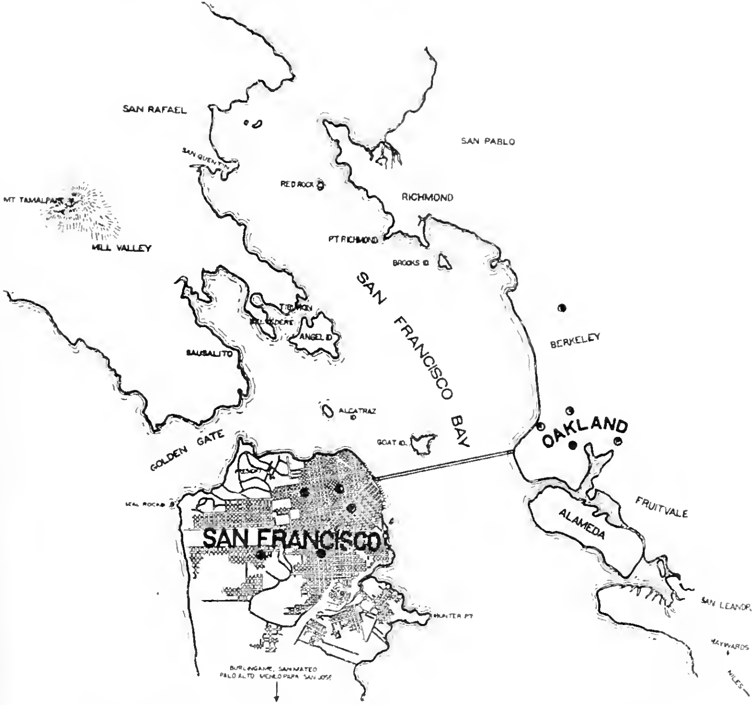
The system described consists of a wire plant of submarine, underground and aerial cables joined to ten groups of automatic switching apparatus housed in ten buildings. Five of the buildings are in San Francisco, four are in Oakland, and one is in Berkeley.

These notes address themselves principally to the features of the work in San Francisco. They are not intended to be exhaustive. They attempt to record features believed to be of some general interest.

It is contrary to the laws of California to omit, when opportunity offers or can be forced, to make reference to the climate. There are practical reasons why reference should be made to it herein. The nearness of the sea and the prevalence of fogs during the summer control the use of unprotected iron and steel in lines and supports and affect the insulation of cable terminals and apparatus. Though the season of rainfall is short, eight or nine months of the year being dry, enough rain falls during the short rainy season to make moisture problems more serious than in most parts of the United States. Snow and sleet and freezing being practically unknown, the requirements of strength in overhead wires are not severe. Absence of freezing also simplifies the use of iron pipes as lateral underground conduits for cables. Water trapped in such pipes, if it freezes, will crush the cable. Such trapping is not objectionable unless the water freezes. The climate permits outdoor work to be done with economy during the entire year.

The populated area of a city cannot be learned from a mere map of the streets, as streets are established and placed upon maps when they cannot be found on the actual surface. I show, therefore, a map of the gas distribution and one of the electric light and power distribution in San Francisco. Upon these you will see what, in general, is the intense business center and where, in general, the mixed and strictly residence portions lie. Comparing with these the map of the underground and aerial distributions of the wire plant under description, you will see that the three correspond in a general way.

The design of the system was begun in September, 1906, five months after the earthquake and ensuing fire. These designs were general and particular; general in the sense that they were based upon a development study which attempted to forecast the growth of the system up to 1925, and particular in the sense that they called for the construction and assembly of buildings, lines, and apparatus to serve a definite number of subscribers within a definite area. Construction of the work called for by the particular plans was begun in January, 1907. It was completed at the end of December, 1910.

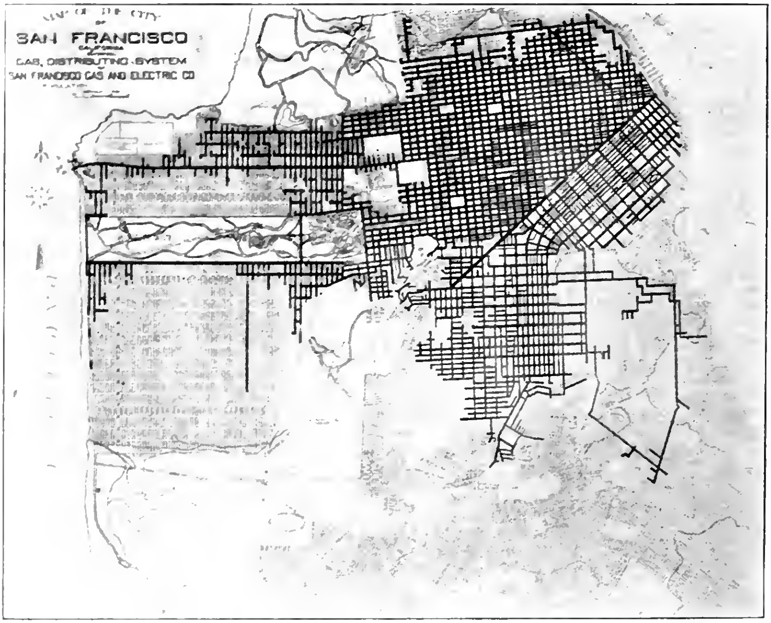


San Francisco and Environs, Showing Ten Central Offices.

Certain features of the work were controlled by a franchise and by a contract. The franchise authorizing the construction of the system stipulated that $2,000,000 should be spent in good faith during the first year after beginning actual work, $3,000,000 during the first two years, and $4,000,000 during the first three years.

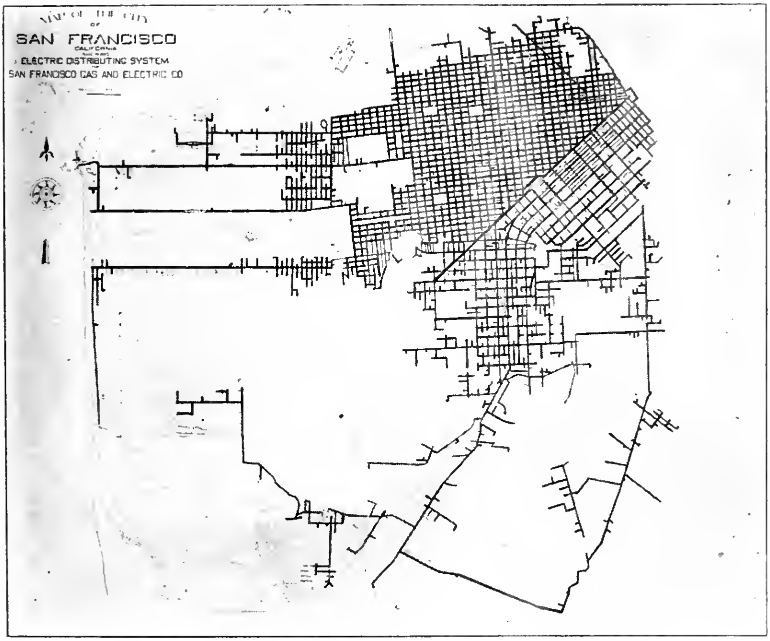
These requirements were carried out. It will easily be understood that they added interest to the task. At certain of its stages the interest was more acute than pleasant.

A large part of the wire plant is carried in underground conduits, and the remainder on poles, in buildings, on fences and back walls. The conduits contain ducts enough to carry the cables which will be required for growth until 1925, unless the population and prosperity of the city shall increase more rapidly than was laid down by the original study. The main conduit runs are composed of vitrified terra cotta or of bituminized wood-fibre. Laterals are of these materials and iron pipe. The ducts in a trench vary in number from four to eighty; and whatever the number may be, there are nowhere more than four ducts in a horizontal layer. That is, a line of eight ducts is four wide and two high, and a line of eighty ducts is four wide and twenty high.



Gas Distributing System, San Francisco.

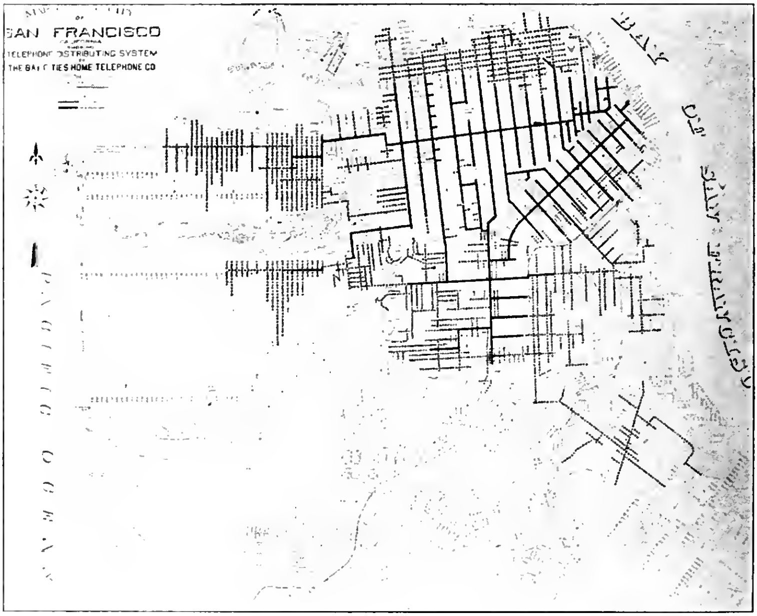
The ducts are enclosed in concrete, whether the duct material be tile or fibre. The thickness of the concrete envelope at the maximum is 3 in. on top, bottom and sides. In less severe conditions, the thickness of the side concrete is 2 in. The concrete envelope serves the usual purposes of protecting the ducts against attack and other hazards. The nature of the earth in San Francisco is almost uniformly well washed sand. Digging is easy, but there are disadvantages. If, for example, a large sewer breaks, heavy rainfall may loosen and carry away great quantities of sand, causing a hole which will enlarge steadily during the rainfall. As long as the pavement maintains a roof over the hole, the latter is not detected. If it grows large enough to undermine a water main, that may open up one of its own joints and assist the washing-out process. A conduit not well protected by a concrete envelope will fall apart after the sand around it is washed away by an accident like this. The system described already has experienced such and similar accidents and in all cases the conduit has maintained itself as a beam across the gap. A thinner or poorer concrete envelope would have been less useful.


MAP OF THE CITY
OF
SAN FRANCISCO
CALIFORNIA
ELECTRIC DISTRIBUTING SYSTEM
SAN FRANCISCO GAS AND ELECTRIC CO

Electric Distributing System, San Francisco.

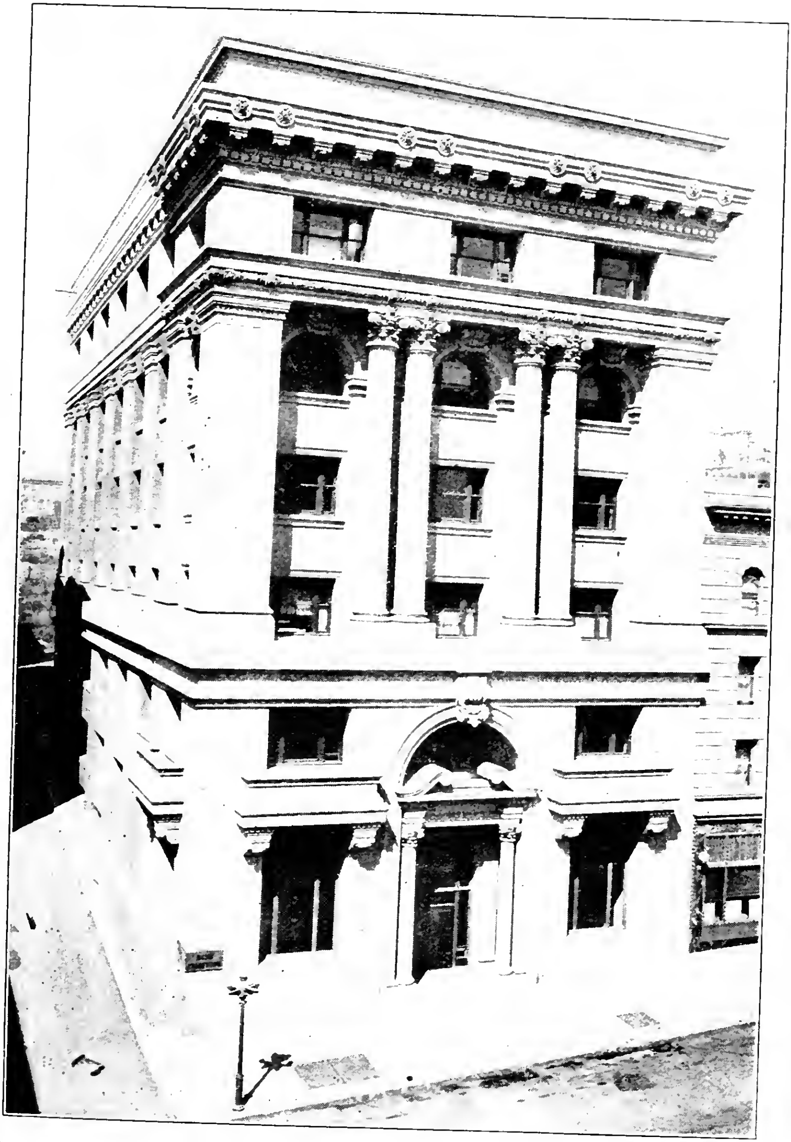
The San Francisco portion of the system contains 2,055,000 ft. of duct 3½ in. in diameter laid in about 240,000 ft. of trench. These ducts enter 1089 vaults or manholes. These are all of concrete molded in wooden forms.

The streets of San Francisco contain the usual assortment or kinds of pipes and there have been considerable duplications. There are several independent and competitive gas and electric systems and there have been more than there are now. Clear conduit space was found to be scarce and records of existing pipes and conduits to be scarcer. No one expects to find correct records of what things are in the streets of any city, but there are some advantages in having access to records even alleged to be correct. In San Francisco in 1906, there were no records because the fire had destroyed them. The experience gained in the work under description increased the writer's indifference as to pipe records as a prerequisite. It was found about as convenient to use the streets themselves as records, and no places were found where at least one more conduit system could not be placed. In one instance it was necessary to lay a section of conduit 20 ft. below the street surface, but at *some* depth a place always could be found. In this deepest place the difficulty was that four street-car tracks crossed just above the trench at that point and there was a great deal of pipe congestion as well. No convenient way of opening a trench 20 ft. deep across the busiest street of the city and in loose sand suggesting itself, the work was tunneled. The conduit having been laid in the trench and some sand packed around it, the tunnel was tapped from above and filled with sand by means of water. Two years later the street surfaces at that point are still level.


OF
SAN FRANCISCO
CALIFORNIA
TELEPHONE DISTRIBUTING SYSTEM
THE BAY CITIES HOME TELEPHONE CO
BAY

Telephone Distributing System, San Francisco.

Reminders of the days of '49 are almost entirely personal since the fire and earthquake and those who can remember "when the



One of 5 Central Office Buildings, 333 Grant Ave., San Francisco, Calif.

water came up to the foot of Montgomery street," are growing fewer. The conduit near Montgomery street in Pine street, however, is laid through the well-preserved oak timbers of a derelict craft, though the waterfront has been a quarter of a mile away for forty years.

The construction of the conduit system was assisted by the fact that a large part of it was laid in the area swept by the fire. The normal business of the city was transferred to the unburned regions immediately after the fire and remained there for about a year and a half. The local regulations covering street openings were interpreted liberally enough by the city authorities to allow us to have open at one time more and longer trenches than would have been permissible if the business of the city had been going on in its former, natural place.

Though one may place little dependence upon the usual records of underground structures as an aid in laying new ones, it need not follow that he considers reliable records impossible to make. The public records of San Francisco now contain accurate data as to the position, character and dimensions of at least the conduit system here described. These records were placed in the city's hands as the work went on. It should be possible for future underground work to be planned with reference to these records, as no earthquakes so far recorded have been severe enough to change the position of conduit systems in the streets. Nothing in San Francisco suffered less earthquake damage in 1906, by the way, than the conduit system and the cables in them.

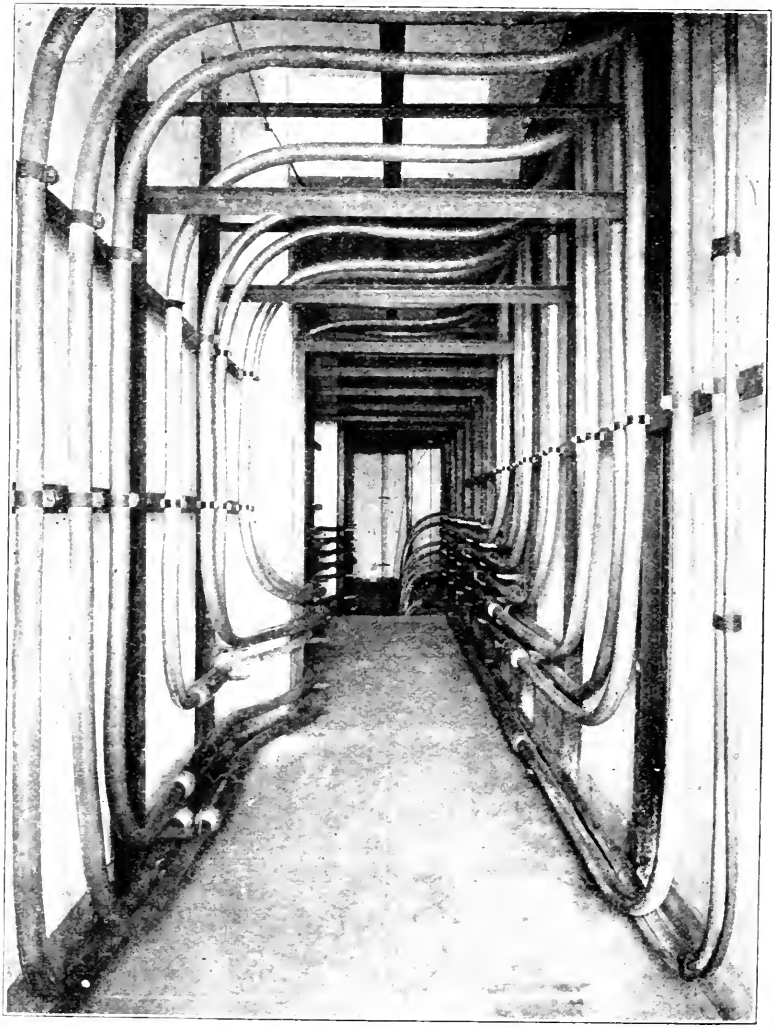
Subscribers' lines, radiating from the various central offices through the conduit system, are carried in lead-covered cables. These pass to terminals in buildings, on back walls and on poles. The latter either form pole lines running along the streets or are on private property. The regulations under which the system operates permit the setting of poles on streets wherever the business requires it, except in a small downtown area. The policy of the construction, however, was to restrict the street pole lines as much as possible, not in order to save money, but in order to establish the best conditions for the people and consequently for the owners of the system. These poles on private property do not form pole lines, but are distributing points connected with the main wire plant, in most cases by a lateral cable carried underground from the main conduit system through an iron pipe.

In ordinary transmission of power by means of electricity, the character of the line circuit is usually determined by applying Kelvin's law, or some other, intended to tell what type of line shall be chosen for least operating cost; a line which is so designed for a certain maximum economy may not achieve it when the cost of the generated power becomes greater or less than that originally assumed. Transmitting speech by electrical means furnishes a line problem somewhat different. What is attempted is to provide lines in which the electrical losses shall be limited enough to enable any two subscribers in the community to talk with not poorer than a predetermined volume, yet to enable any subscriber to talk over long distance trunk lines to another in a distant community similarly equipped.

Telephone engineers are accustomed to determining these limits of commercial telephone transmission in terms of a standard cable circuit of No. 19 B. & S. gauge copper wire, having a capacity between the two wires of 0.06 microfarads per mile; they describe in terms of miles of such cable the transmission attempted or secured. For example, it is customary to say that entirely satisfactory local telephoning is done, without inconvenience or strain, if a subscriber may talk to another in the same community with a quality equal to that between two telephones directly connected through ten or twelve miles of standard cable as described. Long distance transmission is practical for the general public if as good as that, through, say, thirty miles of such cable. Speech, of course, is *possible* through lines equivalent to much more than thirty miles of cable, but is *comfortably* possible for normal persons at that value.

Details of Public Office, Grant Avenue Station, San Francisco.

It will be obvious that a line of heavier wire, or a line specially treated with improving devices, can be of intrinsic quality much higher than the standard cable referred to, so that 1,500 miles of it might equal thirty miles of the standard cable. Similarly, for local purposes, it is not necessary to use cable of as great intrinsic value as the standard, as long as the necessary results are secured in both local and long distance working.

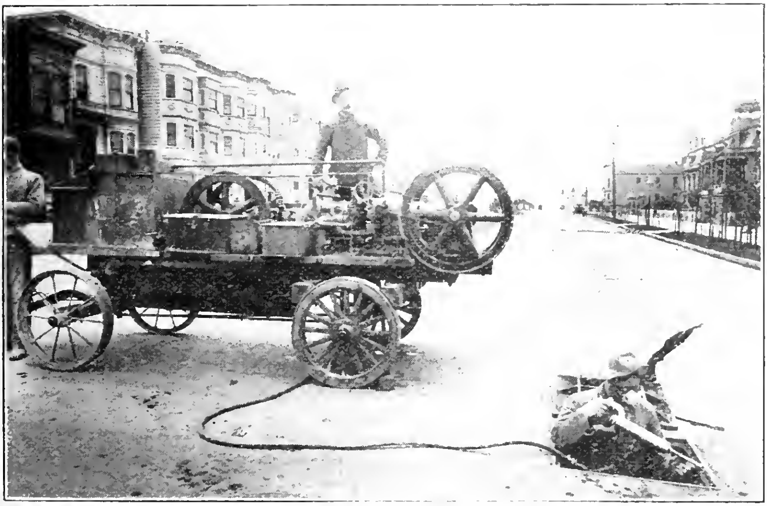


Fifth Floor, Cable Turning Room; Top of Shaft in Distance, Grant Ave., Office Building, San Francisco.

The object of defining intrinsic line qualities in terms of a cable of particular qualities is of course merely *to establish a* *measure* for circuits of this kind, because the methods used in electrical power transmission lines are not conveniently applicable.

In the San Francisco system, by these means, the two subscribers having the longest lines to the central offices joined by the longest trunk lines, can talk as comfortably as if they were connected directly through about nine miles of standard cable. Obviously, subscribers having the shorter lines will have even better means for securing connections with long distance lines, these in turn placing them within practical talking distance of their correspondents in a distant city.

As a San Francisco example of this method of equating the lengths of telephone lines, it may be said that the toll (or long distance) switching centers of the peninsular and mainland portions of the system under description are actually 8½ miles apart. A little over 3½ miles of this length is in submarine cable on the bottom of San Francisco Bay. A little less than 5 miles of it is in underground cable between the toll central offices and the bay shores. The intrinsic quality of the submarine portion is about equal to the standard cable which has been described, but the land portion is of much higher intrinsic quality. The result of joining the three sections is to bring the two central offices within 6½ miles of standard cable of each other, thus saving a telephonic distance of 2 miles, by the expedient of using heavy wire cable in underground conduit, where cables of many heavy wires can be laid with ease, and using smaller wires under the water, where the number of pairs must be large and the cable relatively small.



Portable Air Compressor and Pneumatic Drill, San Francisco.

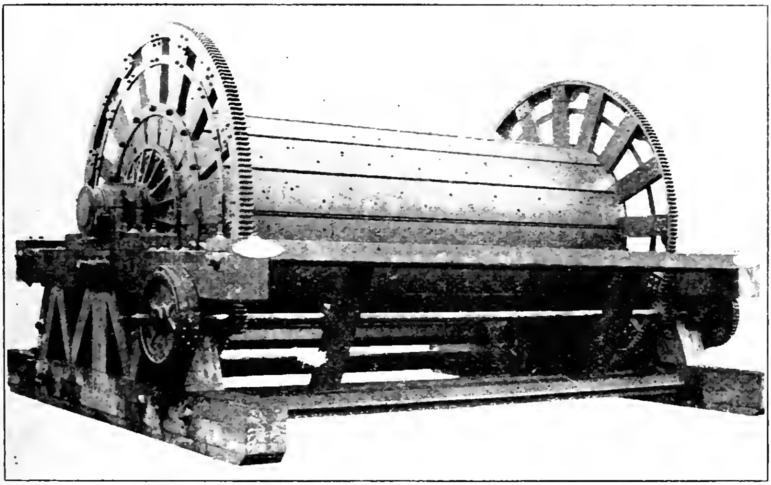
The cables are formed of paper insulated copper wires twisted in pairs and covered by a lead sheath. Speaking generally they are of low capacity. The cables for subscribers' lines are of No. 22 B. & S. gauge wire and those for trunk lines between offices are of No. 20, No. 19, and No. 13 gauge, the latter forming the land portion of trunks between switching points on the mainland and peninsular sides of San Francisco Bay. These cables form the entire wire plant with the exception of that carried by drop wires and interior wires. Drop wires are those which extend through the air from cable terminals on poles, walls, and fences. Where extending from terminals on poles, the drop wires are of hard-drawn copper or copper-clad steel, are insulated with rubber covered by a braid and are twisted in pairs. The tensile strength of No. 16 hard-drawn copper wire or of No. 18 copper-clad wire is sufficient for the requirements of the climate, as no load of snow or sleet ever has to be carried. In regions less fortunate in this regard, the corresponding necessary sizes are No. 14 and No. 17.

Distributing wires from wall and fence terminals are carried in right lines through rings. They require little tensile strength, as the distance between rings is small. The wire is of No. 18 B. & S. gauge soft copper. Where terminals are located inside buildings, as is the case in hotels, apartment houses, and office buildings, No. 19 gauge interior wire leads directly from the terminal to the telephone instrument, if the building be small, or from a subsidiary terminal on its own floor, these floor terminals being connected by vertical cables to the main terminal, usually in the basement.

Cable conductors being insulated with dry paper, and the requirement being that this paper always shall be anhydrous or as nearly so as possible, an air-tight moisture-proof device is necessary for terminating a cable, providing some way of attaching the drop wire or interior wire. At the time the San Francisco system was designed, the two best ways of terminating small cables were, first, to end them in a separable wooden box whose sides contain binding screws and whose inner space can be filled with an insulating compound, thus forming a seal between the outer air and the cable wires, and as a second way, to end them in a separable box consisting of a cast-iron chamber having a porcelain front, the latter carrying the binding screws, the cable conductors being sealed in compound within the box.

The wood box terminal has the disadvantage that its insulation falls during the rainy season in San Francisco. The cast-iron terminal with the porcelain front is serviceable but costly. Terminals developed for use in San Fransico consist of two slabs of porcelain carrying the binding screws, the slabs being so formed as to assemble into a tubular box which may contain the sealing compound through which the paper-insulated wires pass to the binding screws. Terminals of this type are compact, furnish high insulation, are inexpensive, and can be attached to a pole, fence, or wall with maximum ease and simplicity. It is considered that they represent a simple, high-grade solution of what has been an annoying problem.

Recalling that the lines are distributed through cables and insulated twisted wires, it will be understood that the systems contain no bare wire whatever, and so the lines are freer, not only from crosses among themselves, but from contact with power and lighting circuits and from consequent damage to themselves and apparatus. Nevertheless, the general design did not dismiss the electrical-contact-hazard because of the absence of bare wires. It assumed all aerial circuits to be exposed to the possibility of contact with high potentials, including in this exposure not only rubber-insulated drop and ring wires, but all lead-covered aerial cable as well. All lines, therefore, which go far enough from a central office to contain any aerial wire whatever are made to contain thermal and other protective devices, capable of diverting foreign currents of any dangerous amount or kind. These protective devices are located in the central office and in subscribers' premises, protecting the apparatus and surroundings at both locations.



Reel for Submarine Cable, San Francisco, 1909.

Capacity, 25,000 lin. ft. of 3.3 in. Cable, Weighing 7.5 lbs. per ft. Dist. bet. Heads 16 ft. Depth of Winding Space, 24 in. Diam. of Drum, 6 ft, 3½ in. Shaft, 11 in. Diam. Total Weight without Cable, 26½ Ton. First Cable Laid from Reel, Dec. 9, 1909.

All of the San Francisco offices contain main distributing frames of greater height than can be worked while one stands on the floor. They are equipped on both sides with running ladders of the type used in retail stores. The use of these ladders causes no inconvenience and the advantage of saving of floor space has no attendant objection.

All of the San Francisco central office buildings are of fireproof (class A) construction. One is of reinforced concrete. The others have steel frames. Each central office building is of such size as to contain the ultimate switching equipment required by telephones in its district when the system shall have grown to the size indicated by the original forecast. For growth beyond that date, whether it be earlier or later than 1925, additional buildings will be required as main offices and sub-offices.

The capacities of the existing buildings in terms of telephone lines range from 10,000 to 50,000 lines.

The principal building, serving telephones of the financial, retail, and office-building district, is of a size to enable it to house the switching equipment and the general and local offices of the operating company.

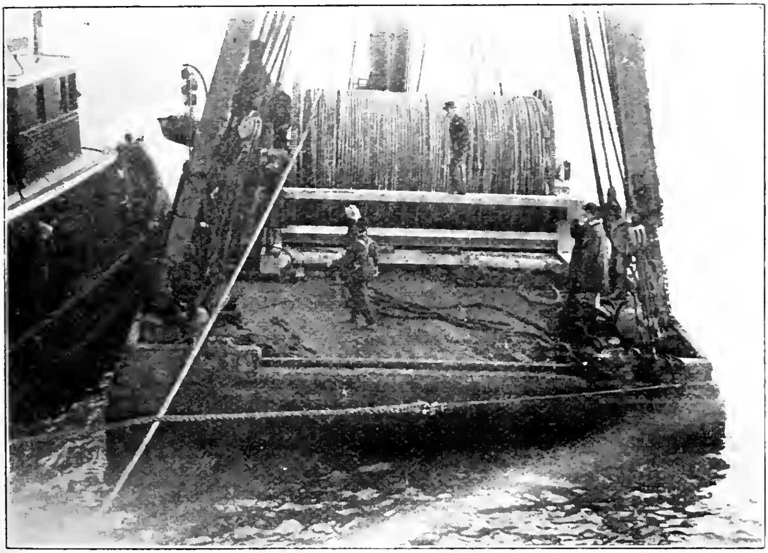
All of the buildings are equipped with fire-excluding means, having wire glass on exposures and in one case rolling fire shutters. The buildings are equipped with stand pipes and with acid-alkali, sand, and carbon tetrachloride fire-extinguishing means. Rooms which contain the electrical apparatus contain no acid-alkali extinguishers, as the danger resulting from the liquid exceeds that likely to result from the fire. A certain modified carbon tetrachloride is the most promising of the several fire extinguishing materials. In the form suitable for this use, it is a colorless, volatile, non-inflammable liquid whose vapor smothers fire. It does not corrode metal or destroy insulating qualities.

The operating room floors in all of the offices are of cement finished concrete without further covering of wood, tile, or linoleum. They are treated with Toch Bros. cement filler. As the floor wears, the cement surface takes on a dull shine; but four years' wear has not shown any sign of cement dust and none seems likely. Untreated cement floors are not permissible in operating rooms containing electrical apparatus, as cement dust vitrifies in an arc or spark, forming a glaze which is a good insulator and is difficult to remove. No such dust can be detected in the operating rooms described.

The switching equipment of the system is of the automatic type. The equipment in the mainland offices is of the three-wire type and that of the San Francisco offices is of the two-wire type. The difference is that the two-wire system uses no ground contact in setting up and taking down connections. The two-wire system, therefore, is preferable and is a later development. The advantages are several. The expense of placing and maintaining the ground connection at each telephone is saved, the instrument itself is simplified and many of the circuit arrangements in private exchanges and central offices are improved.

The San Francisco automatic switches include primary and secondary line-switches, tending respectively to reduce in number the more bulky and costly elements of machinery and to distribute the traffic upon the connecting devices more uniformly.

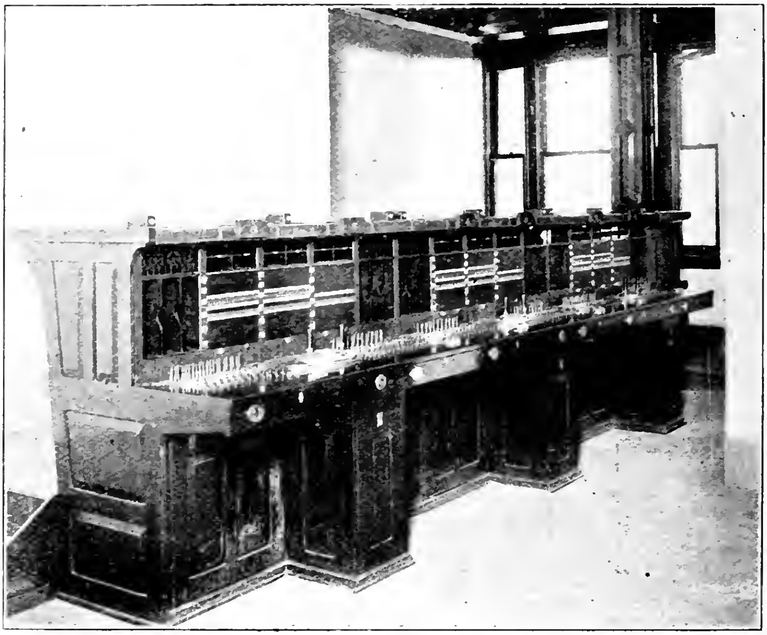
Shortly after the completion of the general design of the San Francisco system, a local telephone ordinance made it inadvisable to sell business and professional telephone service at flat rates and named maximum measured service rate for those classes. This required the design of a system of recording conversations originating on automatic measured-service lines, as no satisfactory method had been developed up to that time. The entire system is equipped with a system of wiring for service meters, so that the calls on any line may be counted automatically. Meters are omitted from flat-rate lines, but a meter may be attached to any line with little labor. The meters count, in plain Arabic figures, up to 10,000 and repeat and only answered calls are recorded. A call which finds a busy line or which reaches an unattended telephone can not operate the meter. A call from a Chinatown telephone to a Chinatown telephone is not recorded, as local service with Chinatown is on a flat rate. A call from a Chinatown telephone to another outside of Chinatown is recorded, as the price of such outside calls is added to each Chinatown flat rate.



Laying Submarine Cable in San Francisco Bay, Dec. 9, 1909.—Leaving San Francisco Shore.

The power plants of the several central-office equipments are of the usual standard type, wherein several sources of primary power are available. They are in advance of former automatic practice in the absence of duplicate storage batteries. A single battery is used in each office and the discharge potential can be kept uniform during charge by the inclusion of from none to seven counter-electromotive force cells in the discharge leads. The method has been found to be entirely satisfactory.

The ratio of business telephones to total telephones in San Francisco naturally is higher than in most American cities. Similarly, the ratio of private exchanges to total telephones is large. Private exchanges in this system are of three kinds, being those having switchboards and human operators, those having inter-communicating key-sets by which each user becomes the operator, and those having true automatic switches on the subscribers' premises. The two types first mentioned are, in general, similar to those used in exchanges for manual central office switchboards. An operator in a private exchange in San Francisco, however, may know by her lamp signals when a distant called subscriber answers her, and so she is not required to listen for that answer. This is a simple but important help, and one which does not exist in manual practice. If desired, such switchboards can be equipped with ways of



Long Distance Switchboard, San Francisco.

preventing even the private exchange operator from hearing a conversation going on through her switchboard. The main central-office equipment being automatic, this private-exchange feature makes the conversation secret.

Completely automatic private-exchange equipments were found useful in apartment houses, which are increasing rapidly in the reconstructed area. The advantage of automatic equipment for apartment house use is that the service is available all day, and every day. With a manual switchboard in the office of the apartment house, there often is not enough traffic to warrant keeping an operator on duty all day and all night, so that during early morning hours it sometimes is difficult to call or be called. The automatic apartment house system obviates this difficulty.

The foregoing description of equipment is limited for the reason that much of the writer's work has been described by others heretofore. Any one who is interested may also find more exhaustive description of the San Francisco equipment in papers by Mr. W. Lee Campbell and Mr. Arthur Bessey Smith, published in the Transactions of the American Institute of Electrical Engineers, 1908 and 1910, and a description of the automatic system in a volume called "Telephony," by the present writer and Mr. Kempster B. Miller.

Discussion.

J. G. Wray, M. W. S. E. (Chairman): We have all enjoyed this very interesting and instructive talk by Mr. McMeen and heard the views of the engineer who has constructed that property,—one of the largest, if not the largest automatic plant in the world.

I will call on Mr. Campbell, of the Automatic Electric Company, who has had much to do with the design and who has manufactured this equipment, to open the discussion.

Mr. W. Lee Campbell: I have listened with a great deal of interest to Mr. McMeen's talk. Probably we of the engineering department of the Automatic Electric Company are in a better position than almost any one outside of the employ of the Bay Cities Home Telephone Company, to appreciate the problems and the difficulties they had in San Francisco and which Mr. McMeen has overcome so successfully. As he stated, this work commenced there just after the earthquake and fire, when the city was a desolation and no one knew where some of the large business establishments which had been in existence before the fire would be located after the fire. It was for the engineer in charge to use his best judgment in forecasting where these business houses would locate, in laying out the system, and I think he was very successful in that. The problem from an electrical standpoint or a circuit standpoint was quite complicated also, because, as has been explained, they had a two-wire system in San Francisco, a three-wire system in Oakland, and a three-wire system in Berkeley; interconnecting those was quite a complicated matter on which the engineers of the Automatic Electric Company and the engineers of the Home Telephone Company spent a great deal of thought. The metering of the service also added complication and the addition of the rapid fire service across the bay with the corresponding toll charges made it still further complicated.

We are glad to know that the system is so successful.

Franklin H. Reed (of "Telephony"): It is pleasant to have Mr. McMeen back and be able to listen to one of his illuminative engineering talks.

I was particularly interested in something that I think many of us have heard little about; what was said of the apartment-house problem and the way it was handled. In New York City—the only place where I am personally familiar with the apartment-house problem—the difficulties Mr. McMeen mentioned, of being unable to get the private branch-exchange attendant from either side when wanted, are frequently encountered, and also the further difficulty arising from the fact that the people who have extensions in the apartment houses are not listed in the directory. If one wants to get John Smith, who lives on 102d street near Morningside, and that is all one knows about it, there is no way to reach him. There are other factors. I hope we may hear more of Mr. McMeen's experience in the solution of the apartment-house problems by means of automatic apparatus before the evening closes.

Arthur Bessey Smith: I am very glad to join in welcoming Mr. McMeen back to this region. The main thing to which I wish to draw attention in connection with Mr. McMeen's talk this evening is the ability which automatic apparatus possesses of adjusting itself to different types of conditions. The doubt has existed in the minds of many people whether or not automatic apparatus could meet the rather complicated traffic conditions which exist in the modern telephone exchange. I think that what has been said tonight, brings out the fact that the apparatus possesses a very satisfactory degree of flexibility.

Albert Scheible, M. W. S. E.: I would like to ask this question: Were any loading coils or their equivalents used in the submarine portion of the cable?

Chairman Wray: Two or three points suggested themselves to me, to which Mr. McMeen may want to make some reference. I noticed in some of the first illustrations, something that called attention to the duplication of the investment which always comes when there are competing telephone companies; also, the duplicate poles and duplicate cable terminals on the rear walls of buildings, and Mr. McMeen's reference to secrecy. I would ask whether the toll board for A. B. work is arranged to provide for secrecy, or whether the toll operator can get in on the connection. Has any provision been made to take care of an unusual rush of traffic making all the trunk lines busy? I would also ask whether the arrangement for automatically recording calls on the meter is such as to provide against such recording, when the called line is in trouble, or when a wrong number has been called. I infer that a record is made in a case of wrong numbers and very likely in certain cases of trouble.

The Author: Answering Mr. Reed as to the directory situation, it is about like this: In San Francisco apartment houses the tenancy varies. Tenants do not lease for one, two or three years. People come and go, particularly in the furnished apartment houses. Therefore tenants change so often one can not keep track of them in the ordinary sense. One thing does not change,—the number of apartments and the number of telephones in the building, usually one line per apartment. In this particular method, each apartment is assigned a telephone number and is so listed; it does take directory space. If you know your friend's apartment number you can get him whether you find his name listed or not. If, however, the tenant is not a transient for a very small fee he can have his name listed in the proper alphabetical part of the book. This practice is followed extensively with hundreds of telephones, without the slightest difficulty.

Referring to Mr. Smith's comment on the practicability of automatic apparatus, the question is so often asked, "Which is the better, automatic or manual appartus, for my case?" I say, "I don't know. Do you?" And he doesn't. It is possible to render an acceptable and salable telephone service by the use of either automatic or manual apparatus. There is no question about that. It has been shown very conclusively.

Mr. Scheible asked about the use of loading coils in the submarine cable: there are no loading coils. The conditions of transmission are, as I stated and as you will see, such that there is hardly need of loading coils for such a circuit. The circuits in those submarine cables are not intended to form a part of an extremely long long-distance line.

In answer to Mr. Wray: His first remark was a statement as to duplication. If you have two telephone systems there must be duplication. It is questionable whether, in the broad ethical view, telephones are benefiting the human race at all. I know they have done things. They have quickened the transaction of business. They may be producing neurasthenia. If so, two telephone systems are worse than one. If a telephone system is a good thing, two may be twice as good. I don't know. About some other man's kind of business I could perhaps tell more.

There is no special secrecy in the toll board. It is like any other. The automatic apparatus brings the call to the long-distance board and there it is handled, broadly, the same as in a toll board serving local manual boards.

As to the provision for unusual traffic, provision is made at the outset for a certain assumed maximum; in this particular instance the capacity of the machinery to do the switching is at the rate of sixteen calls per subscriber's line per day. Sixteen calls per subscriber's line in such a measured service system will not soon be reached. It is a question now whether the plant, designed as it was for flat rates, should not be caused to serve the public on a compromise between flat and measured rates. It is a question whether an automatic system is best used by serving subscribers at strictly measured rates. There is no trouble in giving good service on a measured basis, because the machines are used just about enough to operate well and not be overcrowded.

Mr. Wray asks what would happen if all trunks were busy. I don't know. We have seen them in a heavy trial. San Francisco chose herself for an international exposition in 1915. You can imagine how the people feel in a city that has been five years bringing itself from ruins. They want to celebrate. All that San Francisco asked for was recognition. They were willing to pay for the exposition. New Orleans came to the front and there was a strong fight; in the house committee New Orleans won; San Francisco awoke to the fact that she was liable not to get the exposition she was going to give herself. Contrary to the expectations of some, she succeeded. The signal of the success was in the form of a bomb. Everybody rushed to a window, took one look, and then rushed to the telephone to tell his wife. So far as we know, all calls went through. The traffic was very heavy, but it appeared to be handled excellently. We have seen but one such thorough test.

Concerning automatic calling of a line in trouble. A line can only be in trouble in two ways: in a way that will cause current to flow through it, even though the telephone is on the hook, or in a way wherein it will not;—above and below a certain critical maximum. If it is *above* that maximum, you will have a "permanent signal"—as would be said in manual practice,—and no one can get that line. If, however, the line is in trouble so that you can call it but cannot get your party to answer, your call does not count on the meter.

We take no responsibility for the getting of wrong numbers. In that particular system the "wrong number" question never was any grief to us. If it is not so elsewhere, I pay the compliment to San Francisco people that they use the dials in the right way. One does get wrong numbers, but when he comes to analyze them he finds it is, perhaps, a personal habit of transposition, or he may get the number wrong by failing to look in the directory.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS.

Extra Meeting September 13, 1911.

An extra meeting of the Society (No. 753) was held Wednesday evening, September 13, 1911. The meeting was called to order at 8:15 p. m., with Mr. Ernest McCullough presiding and about 30 members and guests present. There was no business to be transacted, and Mr. H. Gansslen, Assoc. W. S. E., was introduced, who read his paper on "Ball Bearings for Heavy Loads." After the reading of the paper a number of lantern slide views were shown in illustration of the subject. Mr. W. L. Batt, representing the Hess-Bright Mfg. Company, took part in the discussion, illustrating by lantern slide views and samples of ball bearings some uses and points of construction. Discussion was also presented by Messrs. W. E. Symons, E. A. Balsley, J. H. Warder, Ernest McCullough, and the author.

The meeting adjourned at 10 p. m.

Extra Meeting, September 20, 1911.

An extra meeting of the Society (No. 754) was held Wednesday evening, September 20, 1911.

The meeting was called to order at 8:20 p. m. by Mr. W. C. Armstrong, with about 70 members and guests in attendance.

There being no business to come before the meeting, Mr. J. A. Peabody was introduced, who read his paper describing the "Signaling and Interlocking of the New Passenger Terminal, C. & N.-W. Railway." The paper was illustrated by numerous lantern slides.

Discussion followed from Messrs. C. B. Lewis, S. G. Neiler, G. T. Seely, J. S. Robinson, W. E. Jones, and C. R. Dart.

The meeting adjourned at 9:55 p. m.

Extra Meeting, September 27, 1911.

A joint meeting of the Electrical Section, W. S. E., No. 755, and the Chicago Section, A. I. E. E., was held Wednesday evening, September 27, 1911.

The meeting was called to order at 8:15 p. m., Mr. G. T. Seely presiding, and about 60 members and guests present. Announcement was made that the next electrical meeting—the yearly "Steinmetz Meeting"—will be held October 25, when Dr. Steinmetz will speak on "Reactance in Alternating Current Circuits."

Mr. S. G. Neiler was then introduced, who read his paper on "The Electrical and Mechanical Equipment of the New Passenger Terminal, C. & N.-W. Ry." This was illustrated by a number of lantern slide views. Discussion followed from Messrs. Bement, Ravlin and Fowle, with replies and closure from Mr. Neiler. A vote of thanks was tendered Mr. Neiler.

The meeting adjourned at 10:45 p. m.

Regular Meeting October 4, 1911.

A regular meeting of the Society (No. 756) was held Wednesday evening, October 4, 1911. The meeting was called to order about 8:20 p. m., with President Chamberlain presiding and about 75 members and guests present.

The reading of the minutes of the preceding regular meeting, September 6, 1911, was dispensed with as they had already been printed in the Journal. The Secretary reported from the Board of Direction that the following had applied for membership:

No. 86, Charles L. Armsby, Chicago.
No. 88, Albert L. Wallace, Chicago.
No. 89, Thomas D. Mylrea, Chicago.
No. 90, Wm. A. Webb, Gary, Ind.

No. 91, Charles R. Richards, Urbana, Ill.
No. 92, Edward A. Green, Chicago.
No. 93, Robert V. Howard, Oak Park, Ill.
No. 94, Henry W. Lee, Chicago.

Also that the Board of Direction had transferred Mr. Robert E. Belknap to Associate Membership.

There being no further business, Mr. Onward Bates, Past-President of the Society, was presented, who read his admirable paper on "Fundamentals." Remarks followed, bearing on this subject, from Past-Presidents L. E. Cooley, H. B. Herr, and C. F. Loweth, also from Messrs. A. Scheible and W. E. Symons, with a closure from Mr. Bates.

The meeting adjourned at 9:50 p. m.

Extra Meeting, October 11, 1911.

An extra meeting of the Society (No. 757), being a meeting of the Bridge and Structural Section, was held Wednesday evening, October 11, 1911.

The meeting was called to order at 8:20 p. m., Mr. John Brunner, chairman, with about 90 members and guests in attendance.

Mr. Wm. Artingstall was introduced, who read abstracts of his printed paper on the Chicago River Tunnels, their History and Method of Reconstruction. Some lantern slide views illustrative of the topic were shown.

Discussion followed from the chairman and Messrs. R. H. Rice, Samuel Artingstall, C. R. Dart, R. F. Kelker, Jr., with a closure from the author.

The meeting adjourned about 10:45 p. m.

Extra Meeting October 18, 1911.

An extra meeting of the Society (No. 758), being a meeting of the Hydraulic, Sanitary and Municipal Section, was held Wednesday evening, October 18, 1911. The meeting was called to order at 8:20 p. m., Mr. L. K. Sherman presiding, and about 80 members and guests present. Mr. H. L. Cooper was introduced, who gave an interesting illustrated talk on the Water Power Development of the Mississippi River at Keokuk, Iowa. Discussion followed from Messrs. L. E. Cooley, S. T. Smetters, John Ericson, O. E. Strehlow, with replies and closure from Mr. Cooper. Mr. James Lyman moved a vote of thanks to Mr. Cooper for his interesting and valuable address, which was duly carried.

The meeting adjourned about 10:10 p. m.

J. H. Warder, Secretary.

BOOK REVIEWS*

A Treatise on the Design and Construction of Mill Buildings and Other Industrial Plants. By Henry Grattan Tyrrell, C. E., The Myron C. Clark Pub. Co., Chicago and New York. 1911. Cloth; 9 by 6 in.; pp., 490. Price, $4.00.

This book is a much enlarged and more complete treatment of a subject which the author gave to the public in an earlier book. As he states in the preface, it is based upon the author's personal experience of twenty years.

The text is divided into four yarts:

Part I, "The Theory of Economic Design." There are nine chapters as follows: General Features; Location, Purpose and Arrangement; Number of Stories; Walls; Cost of Steel Buildings; Comparative Cost of Wood, Steel, and Concrete Buildings; Roof Covering and Drainage; Lighting and Ventilating. 94 pages.

Part II, "Loads." Four chapters. Static Roof Loads; Floor Loads; Snow and Wind Loads; Crane and Miscellaneous Loads. 22 pages.

Part III, "Framing." Four chapters. Steel Framing; Wood Framing; Concrete Framing, and Northern-Light, Roof Framing. 76 pages.

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*The books and pamphlets noted in these reviews are in the library of this society.

Part IV, "Details of Construction." Twenty-one chapters. Foundations; Wall Details; Ground Floors; Upper Floors; Roofs; Roofings; Composition Roofing; Corrugated Iron; Sheet Metal Roofing; Cornices; Gutters and Downspouts; Ventilators; Glass; Skylights; Windows; Doors; Foot Bridges; Paint; Painting; and Painting Specifications for Structural Steelwork. 206 pages.

Part V, "Engineering and Drafting Departments of Structural Works. Nine chapters. Engineering Department; Estimating Quantities and Costs; Approximate Estimating Prices; The Drafting Office, Its Organization and Practice; Cost of Shop Drawings, and Directions for Exporting Steel Buildings. 79 pages.

The book is unusually well illustrated, there being over 650 engravings, or an average of about 1½ per page. When it is considered that such chapters as painting, estimating, etc., require no illustrations, it is seen that other chapters are very full.

There are no chapters on graphic statics, stress determinations, or computations, as the author states in the preface that it appears unnecessary to repeat mathematical methods so fully treated in other books. It would have been very helpful to many who undoubtedly will use the book if, at the end of each chapter or part, there had been given a brief list of the best books upon the subject treated in the chapter.

The book is of great value—one could almost say indispensable—to one interested in mill building, or any kind of building construction.

The chapters on painting and ground floors—both important subjects—are very complete and satisfactory; also, other chapters thoroughly treat their subject. Yet, if one is inclined to be critical, there is room for criticism and difference of opinion.

In Part I, on Theory of Economic Design, while it contains many valuable suggestions to the casual worker in this field, and is somewhat new in books of this nature, yet it is a subject so full of possibilities that one cannot help the wish that the author could quickly pass over ten more years of experience, during which time he had compared his own ideas with those of both professional and business men, and then give us a revision of this part.

In many places in the book there is a tendency to make statements without sufficient qualifying clauses, but upon reading further we find the matter corrected. To mention one instance only, in chapter VIII, the author starts the chapter by stating that "any kind of roofing that will withstand the action of heat and cold, wind and rain, snow and ice, will be satisfactory." Further on in the text we find several reasons why "any kind of roofing" is not satisfactory for a specific condition.

In the chapter on Concrete Framing, the author states in the preface that "only a brief review is made of a subject which has been completely discussed by recent treatises." The reviewer feels that the author should have left the designing end of this subject entirely to those recent treatises and not introduced the "author's formula," which is not scientific, and the time for original formula has passed. The reviewer further feels that what is said about the design of columns is positively dangerous. In speaking of spirally reinforced columns, the statement is made that the part inside the winding may be loaded to 1,000 lb. per sq. in. without saying a word as to the nature of this winding. No. 24 wire spaced 4 in. apart apparently is just as effective as ½ in. round continuous spiral with a 1½ in. pitch or spacing. It is further considered that if the author had read carefully some of these recent treatises, he would have modified his statement that the only reason for using "high tension bars" is a commercial one and not scientific.

In another chapter we read that "rock is too hard and non-resisting" for building foundations, yet how glad we all are when we find rock just at the right depth. And when we get to Pile Foundations, a new pile formula greets us, but after looking a little closer the old reliable Engineering News formula appears, modified a little, and dressed up in new clothing, for which we see no reason.

Throughout the book is much cost data, and we feel that the reader is not sufficiently cautioned in its use. The experienced man does not need to be cautioned, but the inexperienced man, who will be the larger user of this material, needs repeated cautioning, for while most of the figures, within the knowledge of the reviewer, appear as correct as can be given without a lot of explanatory matter, yet there are some which under certain conditions of labor and location would lead the man far from the mark. Nevertheless these criticisms are incidental and cannot detract from the large mass of very useful information given. W. A. H.

THE THEORY OF STRUCTURES. By Charles M. Spofford, S. B., M. Am. Soc. C. E. Hayward Professor of Civil Engineering, Mass. Inst. of Technology. McGraw-Hill Book Co., New York. Cloth; 6¼ by 9½ in.; xiii+; pp., 411; 314 cuts in text. Price, $4.00.

A careful reading of this book gives the impression that the author has at last put in print class notes, no doubt previously mimeographed, which he has used for instructional purposes with success. The style possesses the brevity characteristic of carefully prepared notes, but is full enough for all practical purposes. While intended as a text-book, the method of presentation makes it an admirable work of reference.

The influence line is used freely throughout the work, and is introduced at an early stage. Nothing like this use of the influence line occurs in actual practice, but the fact that for some structures a consideration of the influence line is necessary, leads one to commend the author for giving it such consideration. In no way can a student become more familiar with the behavior of various structures under load.

The author would violate all precedent by neglecting to go fully into the design of a plate girder. He could not fly in the face of precedent, so the plate girder is given a whole chapter of 41 pages, or about 13 per cent of the text. If the plate girder is a complete structure, then it is the only example in the book of the design of a complete structure. The endeavor throughout has been to present the theory of framed structures; a statement of all approved methods of computation; and the design of the more important elements of which all structures are composed. Statically indeterminate structures will be treated in a future volume, approved approximate methods for ordinary types of such structures being given in the book under review.

A large amount of information has been compressed into a comparatively small space, the treatment being all up-to-date with simple mathematics. E. McC.

TRADE CATALOGUES.

AIR COMPRESSORS. The Ingersoll-Rand Co., No. 11 Broadway, New York Bulletins—*Form 3007—Class P. B.* Duplex Power-Driven Air Compressors. Pam. 6 by 9 in., 24 pages, including tables and many fine half-tone illustrations of the machine as a whole, and of some details of construction. A characteristic of these machines is the massive solid construction and simplicity of design and operation, which, with the high quality of the materials of construction and the perfection of mechanical design and finish, insures an unlimited capacity for hard work. Ready accessibility to all working parts and thorough lubrication secured by the flood system, are points to be appreciated by the operators. Automatic control of the pressure and regulation of output are provided by suitable governing devices.

Form 3109, Class N. F.—1, is a 12 page pamphlet, same size as above, with illustration and tables which show steam driven single-stage straight line compressors provided with twin fly-wheels, center crank of enclosed type, and with steam and air cylinders placed tandem. The air inlet and discharge valves are carefully designed for the work to be performed. In the smaller size of machines the inlet valves are of the "Direct-lift" type, but the larger machines are provided with the standard "Hurricane inlet valves." On all sizes of machines the discharge valves are of the standard "Cushioned direct lift" type.

Form 3210, Class N. E.—1, is another 12 page pamphlet of the same size and with illustrations and tables pertaining to *power-driven,* single stage, straight line air compressors. This machine is somewhat simpler than the preceding as the steam engine part is omitted. The air cylinder is mounted on a substantial main frame, the piston being operated from a center crank shaft carrying a band wheel and fly-wheel. The air valves are substantially the same as in the machines N. F.—1.

VULCANITE CEMENT.

Sundry pamphlets published for gratuitous distribution by the Vulcanite Portland Cement Co., Land Title Bldg., Philadelphia, Pa. Capacity, 2,000,000 bbl. per annum.

Hair Cracks or Crazing on Concrete Surfaces. Pamphlet No. 4, by Albert Moyer, Assoc. Amer. Soc. C. E. 8 pages.

It is claimed that Vulcanite cement contains a greater proportion of fine flour than most other cements and which is so impalpable as not to be determined by use of a 200 mesh sieve, but other means (by physical apparatus) are necessary to determine its amount. It is this fine flour cement which is brought to the surface of the concrete that by contraction develops the fine hair-cracks termed crazing. This can best be seen when the concrete is troweled down to a smooth surface. The remedy is the removal of the thin surface of neat cement, by the use of an acid wash or by keeping the surface of the concrete quite wet until after it is hardened. The essay explains this matter quite thoroughly and the method of applying the corrective. It does not appear that the crazing indicates any weakness of the concrete or mortar, for it possesses full strength. It also appears that this brand of cement possesses unusual strength and is very uniform in quality, also that it is slow setting but quick hardening.

Cement Sidewalk Paving. Pamphlet No. 7, by the same author. 32 pages, illustrated.

This treatise gives detailed information on the construction of cement concrete slabs built in place. To secure permanency, the cement stone slabs must remain hard and tough; a good foundation must be provided, which, with the earth below, must be thoroughly and evenly tamped, and effective sub-drainage must be provided that water may not collect, which by freezing would heave the pavement out of place. To secure strength, the aggregates must be proportioned to secure maximum density. As Portland cement concrete expands and contracts by variations of temperature, practically the same as steel, it will be understood why it is necessary to provide for such physical changes. Experience has shown that the slabs should, as a rule, not exceed six feet in width, and that the blocks should be cut entirely apart at the joints, with a space of ⅛ in. to ¼ in. to allow for expansion. Care must be exercised that the top coat follows directly after the main mass of the slab has been put down, that there may be no separation of the two parts. Rules and instructions are given to secure good results. A table is given of proportions of cement, sand and stone or gravel, to secure a good concrete mixture for pavements, also a list of appliances to assist in securing economical and satisfactory results, with illustrations of various steps of the work. The use of a non-volatile mineral oil mixed with the concrete has proved of great value in some cases. Instructions for doing this, and the quantity necessary, are given. The protection of the newly made pavement from excessive drying out by sun or wind, and of trespassing over the surface by curious or careless people, must be given to secure good work.

Reinforced Concrete for Houses. Pamphlet No. 8, by Benjamin A. Howes, Engineer. An address given before the Association of American Portland Cement Manufacturers, Hotel Astor, New York, Dec. 15, 1909. Reprint from the Concrete Review, Philadelphia, Vol. IV, No. 5, 26 pages. Many beautiful illustrations of houses of this construction, or parts thereof.

This address is full of interest and the author makes very clear and insists upon the difference between a concrete house and a house built of other material, as brick or wood, with a Portland cement stucco plastered on the outside. The one is fireproof while the other is not. The illustrations explained in the text show interior work as well as outside appurtenances constructed of concrete, all of which are very pleasing. Among the latter are garden benches, lantern posts, and fence posts. Some excellent examples of such work, including drinking fountains, can be seen in our own Lincoln Park.

The description of the work executed by the author is clear, easy reading, and interesting. It is a cause of regret that the combination of an architect and an engineer familiar with concrete work does not oftener occur, and thus secure more structures possessing the excellent qualities of those shown in this pamphlet. It is to be hoped that the lecture and the examples of concrete construction shown may turn the attention and study of the younger engineers and architects in this direction.

Concrete Surface Finishes. Pamphlet No. 10, by the same author; 12 pages; colored illustrations.

Much beauty can be obtained with concrete, whether in mass or as a stucco, by the selection of the stone for aggregate and also by the use of terra cotta or enameled tile in the face of the work. The shade, color and texture of the surface can be greatly modified, as shown in the colored illustrations. To get good effects, after the work has been done the surface mortar needs to be removed, more or less, to expose the selected pebbles or fragments of stone. The final effect of color depends mostly on the aggregate used and exposed to view. While the surface is still green and comparatively soft it is scrubbed with brushes and water to clean out the cement mortar and reveal the stone fragments. The selection of the aggregate and its disposition through the mass is of great importance. It is generally necessary to conclude with a dilute acid wash to brighten up the stone surfaces. But this acid wash should not be strong—composed say of one part of commercial muriatic (hydrochloric) acid to six parts of water. One sample shown was based on the use of red marble dust mixed with the sand. This rose-colored surface would be very effective, as in panels alternating with the ordinary gray color of the sand and cement. Other samples are shown where marble dust or marble chips of two colors, ¾ in. size, are mixed through the face of the work. A reading of this pamplet and a study of the illustrations will give many hints for ornamental work in concrete surfaces.

Uses of Mineral Oil Mixed Concrete. Pamphlet No. 9, by Albert Moyer, Assoc. Amer. Soc. C. E. 8 pages.

The oil to be used in connection with Portland cement mortar or concrete should be non-volatile mineral oil, and not very fluid. The alkaline character of the cement assists in emulsifying the oil, which is added after the water has been mixed through the cement and sand. The effect of the presence of the oil in the mortar is to retard the drying out of the water, with the result that the setting of the cement is somewhat retarded and a greater density is obtained in the mortar or concrete. The quantity of oil to be added is 5% to 15%, and with the greater percentage of oil there is the greater delay in the hardening and setting of the cement, with perhaps some lessening of tensile strength. But experiments and study of results indicate that there is less change of volume (contraction) if oil is present than otherwise. The sample pat of cement mortar sets and hardens in air more like a corresponding pat without oil that was hardened under water. The author considers that a mineral oil, properly added to concrete, will prevent the presence of cracks, will make the concrete less pervious to water or other liquids—more dense in other words—and thus give a material better adapted to waterproof construction, as floors, drains, cisterns, etc. The author suggests the use of non-volatile mineral oil mixed with cement stucco for outside or inside work, and gives a formula and directions for use, which have the endorsement of his own experience.

Concrete in the Country. Pamphlet No. 11. Published by the Association of American Portland Cement Manufacturers, Philadelphia.

This essay is intended for distribution among the farmers to show them how Portland cement may be advantageously used in concrete work on the farm. The materials, what they are and how they are to be used, the tools necessary, how to mix the concrete, etc., is set forth fully and clearly, with appropriate illustrations. With the comparatively small amounts of concrete that would be needed in any job in the country, it is obvious that hand-mixing is to be employed. The book describes some of the practical points in such work, and the method of procedure, including the proportioning and measuring of the components, broken stone, sand and cement. Of great importance in such work is that of *forms*, which are almost always made of wood. The object of these forms, how they should be put together and held against displacement due to the weight of the wet concrete placed within them, is stated clearly and with appropriate illustrations.

Reinforcement—principles involved, what it means, kinds, etc.—is also considered. Uses for concrete in the country are numerous, as sidewalks and floors, the construction of which, with illustrations, is described in detail. Also foundations and gutters so necessary about farm buildings, and many appliances and accessories, as driveways about the barn and carriage house, washing floors, feeding floors for stock, manure pits, and cisterns, water troughs, dipping tanks for stock, milk houses, and milk vats, root cellars, duck ponds, walls and steps, etc.

There are many other useful contrivances for the country dweller which can be satisfactorily constructed out of concrete by anyone of fair intelligence who is at all handy with tools. This little book is full of suggestions for such an one, besides giving, in many cases, tables of quantities and costs.

LIBRARY NOTES.

The Library Committee desire to return their thanks for donations to the Library. Since the last publication of the list of such gifts, the following publications have been received:

MISCELLANEOUS GIFTS.

McGraw Publishing Co.:
    McGraw Electrical Directory, Electric Railway Edition, Aug., 1911.
McGraw-Hill Book Co.:
    Theory of Structures, Spofford. Cloth.
Charles W. Standiford, New York:
    Report on the Physical Characteristics of European Seaports. Pam.
John Wiley & Sons:
    Rock Minerals, Iddings. Cloth.
George O. Squier:
    Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires. Pam.
A. N. Talbot, M. W. S. E.:
    The Engineering Teacher and His Preparation. Pam.
Chicago Bureau of Public Efficiency:
    Administration of the Office of Recorder of Cook County, Ill. Pam.
G. C. D. Lenth, M. W. S. E.:
    35th Annual Report of the Department of Public Works, Chicago, 1910. Cloth.
Western Australian Institution of Engineers:
    Proceedings, Vol. I, No.1, October, 1910. Pam.
    Inaugural Address of J. Thompson. Pam.
E. L. Corthell, M. W. S. E.:
    Engineering and Commercial Conditions and Problems in Latin America. Pam.

EXCHANGES.

American Society of Civil Engineers:
    Transactions, Sept., 1911. Pam.

American Society of Mechanical Engineers:
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Journal of the
Western Society of Engineers

VOL. XVI NOVEMBER, 1911 No. 9

FUNDAMENTALS.

Onward Bates, M. W. S. E.

Presented October 4, 1911.

I rashly accepted an invitation to address the Western Society of Engineers at this time, and before I had determined in my mind what I ought to say to you, was asked by your secretary to name my subject so that it could be announced in advance of the meeting. This inquiry put me in a quandary, for I had some rambling ideas which I thought would interest our members if I could collect and dress them with proper words. But it was difficult to find a title which would include the probable result of my efforts, and cover many subjects, indifferently treated. It would not do to call it the "Engineers' pigeon hole of more or less relevant considerations," for that might create an impression of lightness or frivolity, and the title itself must have something attractive and suggestive about it—more important than the name of the writer. Engineers are interested in subjects, and if the subject advertised does not strike their fancy, they will not come to hear it discussed, no matter by whom the discussion is presented. So, following the example of distinguished public speakers, in the pulpit and out of it, a subject was sought which could not fail to interest you, and in looking for a starting point the word "*Fundamentals*" seemed to claim the distinction of being at the bottom of all engineering practice, for all of us are aware that a fundament is a foundation, and that the whole theory and practice of the profession is based on its foundations or fundamentals. It is a fortunate choice for me, since it permits me, in my arguments, to build any form of structure which rests upon a foundation, giving me great latitude in the presentation of the subject, and if, with this privilege, I am not able to lead your thoughts in stable and upright lines it will be clear that there is something wrong with my fundamentals.

In discussing engineering fundamentals, it may be well to begin with the engineer and to consider what he is, where he came from, how he became an engineer, what he is here for, and what is his ultimate purpose. In the first place, he is not fundamentally different from other people. He is, or ought to be a man, the best kind of a man. As to where he came from, it may be that he was born in Europe, Asia, Africa, the Islands of the Sea, or our own America. He does not come from any particular race, or nation, or family. He belongs to no particular class or grade of society, although none of us will accept him as a complete engineer if he is not a high-minded and estimable man. As to how he became an engineer, it is to be hoped that it was from his own choice, anticipating an honorable and interesting occupation, in the pursuit of which he would find satisfaction and enjoyment. To the choice of the profession must be added study and training in the schools of learning and of experience. He is here to do his duty, and his ultimate destiny is that of all good men. He is born into the world just as other men are and he dies as others do, and his beginning and his end are probably the same as if he had followed some other profession. He is built from standard specifications and his physical and mental attributes are like those of all men. It is a mistake to think engineers are naturally different from the rest of humanity. An engineer may think himself to be a different and superior being when compared with those who are not engineers, and in this belief lead a segregated existence, but he cannot maintain such a position by the theory of moments. There is no way by which we may escape the necessity of taking our places and doing our duty in the midst of a community of men.

Let us examine the engineer critically, sound him to bed rock, expose his fundamentals, and see if he is moulding his character and building his profession on a sufficient foundation.

Whenever a civil engineer makes a formal address to his fellows, he follows the practice of the surgeon who told his patient that an operation on him "was not really necessary, but then you know, it is customary," and proceeded to cut him open. I follow this time-honored practice and, as usual, quote Telford's famous definition, to wit: "The profession of a civil engineer, being the art of directing the great sources of power in nature for the use and convenience of man," etc. Thus we assume a sort of divine mission in this world. We become custodians of the forces of nature and guardians of the material interests of mankind. We speak of ourselves as the pioneers of civilization, and we claim that the glories of this twentieth century are due to our conserving care, and our benevolent exploitation of nature's wealth, for which all men who are not engineers become our debtors. I remember at an annual banquet of this society when this country was rejoicing in accounts of the prowess of our arms in the Philippines and in Cuba, one of our distinguished members in a speech claimed, with great and convincing eloquence, that all of the credit of victories won was due to the engineers, and we engineers who were present, acknowledged the fact with modest but tumultuous applause. Now this is all very good and most encouraging when indulged in among ourselves, but it might be disputed in an open forum, and it is to be noted that in public the engineer stands serenely on his own dignity, and does not demean himself by disputing the common people. We are notorious for our modesty, and do not sing our own praise on the streets, although there are times and occasions when this actual or assumed modesty causes us to fail in securing justice for our profession and its members. Still there is to be found here and there in addresses and professional papers, an intimation that we who do so much and carry such great responsibilities for our fellow men, are not properly appreciated and rewarded in proportion to our deserts. If it be true—and I fear it is at least partly true—that we put up a stiff front to the world and keep too much to ourselves, as if we were nursing a grievance, with the consolation that insofar as we are personally concerned, virtue is its own reward; then is not the attitude which we choose to take toward the world imitated in some degree toward members of our own profession? It is not possible for one engineer to be proficient in all branches of the science which are practiced at the present day. This leads to specializing, and one who practices a specialty is apt to overvalue that specialty and to undervalue the specialties which fully occupy the talents of other engineers. This leads again to the assumption of particular titles by the practitioners of specialties. There are a number of such titles which are warranted by general consent of the profession at large, among which are those pertaining to the four divisions represented by the National Societies. In addition, the number of titles assumed by individuals is constantly increasing. The list is already too large for me to attempt to enumerate, but I may mention as the last ones which have come to my notice in printed matter those of *Acoustical Engineer, Illuminating Engineer, Literary Engineer,* and *Sales Engineer.* It really seems time for the regulation—if such a thing be possible—of the use of any engineering title; but it is not my present purpose to suggest any method of regulation. The variety of titles is quoted as evidence that the profession lacks coherence, and that among its members there is the same tendency to segregation that is shown in our attitude toward other occupations.

Returning to my hypothesis that engineers are different or think themselves different, from other men, the reason for this difference must be either in the natural make-up of men who elect to be engineers, or in their training and subsequent associations. My observation leads me to believe engineers to be naturally like other men and that the latter reason must prevail. It may be that an early mistake is made in assuming engineering to be an exact science, and that this idea is so drilled into the engineering student that he can never be entirely free from it. It is common to speak of some boy as being fond of mathematics and that in consequence he will make a good engineer, and yet practicing engineers find their work hampered when their assistants place too much reliance on mathematics and other subjects taught them at school. It is true that the student cannot be too thoroughly instructed in the studies preparatory to practice, and the problem is how to acquire such knowledge and preserve it for use, and at the same time to cultivate and develop the faculties of reason and judgment. As the engineer takes on years and advances in position, he deals more and more with problems which cannot be solved with mathematical accuracy, and which are determined by reason and judgment, and sometimes by conciliation and concessions. The factors of such problems must be ascertained as accurately as possible before what is called by the Supreme Court "The Rule of Reason" is applied. Computations must, of course, be mathematically correct, but these are so often based on variables or assumptions, that reason must be applied in the mathematical operations, as well as in considering the results of them.

In the years of preparation for actual work those who are charged with the education of prospective engineers, carry the responsibility of instructing them in the fundamentals, teaching them to reason, to discriminate, to judge, to decide, and to act.

Referring again to the famous definition of an engineer "using the forces of nature for the benefit of man." We may construct our theory of the profession on this definition and still miss the fundamentals of it; that is, we may fall short in our estimate of nature, and of man, and erect a profession on insufficient foundation, failing to make full use of our opportunities. A study of this definition reveals the noble purpose of the engineer's profession. To direct the sources of power in nature requires some knowledge of the laws of nature. Nature's laws are established by God and are unchangeable and eternal. Not all of them are known and perhaps man may never learn them all. A law in general is "a rule of being or of conduct established by an authority able to enforce its will." It is also defined as "the mode or order according to which an agent or a power acts." The power which makes a law, or a superior power, may annul or change it. Human laws are simply rules which may be good or bad, and are in effect only so long as the maker of them has the desire and power to enforce them. The engineer has to do with the laws of man in applying the laws of nature for the use and benefit of man. Hence the engineer must be a lawyer who can use both natural and human laws. In this capacity it seems most appropriate that while lawyers whose profession it is to conduct lawsuits, or to advise as to the prosecution or defense of lawsuits, or as to legal rights and obligations of parties, are retained because they are versed in human law, engineers are called to act in cases to be decided in accordance with equity and justice. It is well known that the law of the land does not always secure equity, and for this reason special courts of equity are established. Equity means "natural or right, the giving, or desiring to give, to each man his due, according to reason, and the law of God to man"; also "fairness in conflicting claims."

It will be seen from the above that the engineer practices and judges under the statutes of natural law and of human law. Natural law, as already stated, is the law of God and is immutable. A work constructed in conformity to natural law will stand. If natural law is violated, it is sure to fail. When we read of the failure of the Austin dam we know that fundamentals have been neglected, that natural law has been violated, and the result is the punishment for that violation. This does not imply any criticism upon those who built and cared for this dam, for they may have faithfully used their knowledge of natural law, and yet the failure is unquestionably the result of a violation of some such law. Every movement and condition of matter in this universe is subject to the natural law of God, which unfailingly punishes those who neglect or violate it. On the other hand, human law is as fallible as human nature, and is always subject to change by those who are vested with the power of law-making. It is based primarily on the moral law of God but in its application, frequently fails to give to each man his due, according to reason, and the law of God to man; that is to say, it is not always equitable. Experience teaches us that in the application of human law we are not always rewarded for obedience, neither are we always punished for violation, and our respect for such law diminishes in proportion as we observe its inefficiency.

Now, if the engineer is to direct the forces of nature for the use and benefit of man he must, to some extent at least, know the laws which control these forces. Here we find a noble theme, which I can barely mention without being overcome by the magnitude of the subject. The words "water," "air," and "electricity" cannot be used in this connection without bringing to mind the wonderful accomplishments of engineers who had some knowledge of natural laws and endeavored to employ that knowledge for the good of men. When a natural law is once known, the engineer may depend upon it absolutely, even to the extent of risking the life and welfare of himself and his fellow men.

I call to mind a famous controversy which seemed to hinge on the knowledge of a natural law. When James B. Eads built the jetties and opened the mouth of the Mississippi river to commerce, he did so in the face of great opposition from engineers, and was violently opposed by many who were distinguished in the field of river hydraulics, and he only succeeded in obtaining from Congress the privilege of doing this great work on the condition that it should be at his own cost and risk, coupled with that of such friends as had faith to support him. He was not even allowed to choose that pass of the delta which was most suitable for his purpose, but was given the privilege of trying his experiment on another pass not so suitable and situated so that no harm would come if this so-called experiment proved a failure.

We all know the result—how eminently successful it was, and how the pass, which Eads asked for and which was the right one to improve by his method, has since been improved by the corps of

Government engineers which had formerly fought his proposal so vigorously. Eads undertook this work and carried it out under great difficulty in obtaining funds for expenses, and subject to all physical embarrassments which accompany any great engineering work. What was it that gave him this confidence and prompted him to risk his reputation and his fortune, and to labor for years to prove that he was right? It was because Eads was acquainted with a natural law, namely, that the amount of sediment carried in flowing water is proportional to the velocity of its flow; that as the velocity decreases, sediment is deposited and shoal water is made; as the velocity increases it picks up more sediment and carries it away, thus creating deeper water. By confining the flow of water in the south pass to a width limited by the jetties he constructed, the current was increased, the channel was deepened, and for 20 years he maintained a channel, navigable for vessels drawing 30 feet. It was Eads' confident statement at the time of this controversy, that he staked everything on the natural law of God, which brought this subject to my notice in an emphatic way, and has ever since caused me to hold in reverence these natural laws.

An engineer who accepts in full Telford's definition of his profession cannot be a materialist. He comes into the study and knowledge and the application of both God's natural laws and God's laws requiring fairness and impartiality to men. It is not sufficient for him to have just enough knowledge of the law of gravitation to teach him to dam a stream and convert the weight of running water into power, and then to distribute the value of that power among men without regard to equity, caring only to escape penalties imposed by human law. If he is a reasoner—one who looks for fundamentals—he will realize that in directing the great sources of power in nature, he is working in harmony with the Creator who is infinitely wise and just, and his character will be strengthened by the effort to increase his knowledge of these divine laws, and to use that knowledge for the benefit of man on whom the Creator has bestowed this earth. Some knowledge of natural laws is possessed by the most ignorant of men who use this knowledge for their benefit.

Sir Isaac Newton knew very well that when the stem of an apple which supported it on the tree gave 'way the apple would fall to the ground. Any one who did not know that much would be considered a fool, and yet Sir Isaac will for all time be known as the seeker of fundamentals who inquired for himself why the apple fell, and then discovered the natural law of gravitation. History informs us that it was men who looked deep into fundamental reasons who enriched the world with the benefits of science. The true scientist, whether he be an engineer or not, must search out the secrets of the Creator with reverence, and must feel himself spiritually enlightened as they are revealed to him.

Some time ago an eminent electrical engineer told me of sensations experienced by him in his work. I wish I could quote him at length but I can only remember the statement that he was filled with awe at the wonders accomplished, and how this mysterious force could be controlled and utilized when so little is known of its source. It also brought him to the consideration of the temporality of human life when he reflected that the accidental touch of an electrically-charged wire meant that in less than the twinkling of an eye, he would, by this unseen power, be ushered into that world from which no engineer ever returns. Truly, the direction of the sources of power in nature, is a task which should lead man to consider the fundamentals of life itself.

Let us now pass on to the object of the engineer in learning to direct the forces of nature. The definition states it to be "for the use and convenience of man," and we are led to inquire what manner of use and convenience is intended. Is it to make man more comfortable, to feed and clothe him better than before, to add to his life new and greater opportunities of education and pleasure, and in general, to advance the state of civilization which surrounds him? Yes, all of these, and still more: Man is not simply an animal with his desires limited to a full stomach, an agreeable temperature of the body, and pleasing sensations of the mind. Man is a creature with a soul, that something which we do not fully understand and cannot describe, and which, for want of a better comparison, we may liken to the electric energy which pervades the world. We are endowed by our Creator with moral, as well as with mental and physical attributes, and that which is best in us, is to be discovered and conserved and developed. To do this we must begin with the right fundamentals and deal with our fellow men on a higher plane than of natural and human laws. Let us engineers yoke the forces of nature and make the world richer and more comfortable and pleasant to live in, and let us not forget to practice and to instill into the lives of others, the moral relations which should exist among men, and which yield greater returns than the mere catering to the desires of body and mind. Let him who believes the object of engineering is limited to the production of beneficial physical conditions which may profit men if they choose to avail themselves of those conditions, consider the length and breadth and depth of Telford's statement; and if he is not devoid of reason, he will get some idea of the responsibility and dignity of his relationship to other men.

The engineer is accepted among men as an arbiter between them, acting under the laws of nature and the laws of man. He must respect the laws of the commonwealth, and in addition, he is, in cases where the common law is insufficient to secure right ends, selected and deputized to make decisions according to the laws of equity and justice, which are the laws of God. In every agreement for the performance of engineering work the engineer is charged with the duty of deciding disputed questions between the parties to the contract. It is common to specify that his decision shall be final and binding upon both parties. He is the judge of quality and of quantity and of all the covenants between the parties. Indeed, some contracts give the engineer such authority that if literally construed, would enable him to deprive one of the parties of life, liberty, and the pursuit of happiness, guaranteed by our national constitution. Such extreme cases of delegated power are, however, to be taken as attempts at over-reaching by the party drawing the contract, and though it may be agreed upon between the parties that no appeal shall be taken from the decision of the engineer, such an agreement must fail as subversive to the natural rights of men, and contrary to the law of the land.

In line with the powers given to the engineer in the performance of contract work, he is becoming more in demand, as an arbitrator in cases of dispute between the parties to a contract. The fact that the covenants entered into for engineering works involve technical questions of quality and of quantity and of processes, of feasibility and of capacity, makes it difficult and almost impossible for some disputes to be settled by the ordinary appeal to courts of law, and arbitrators are selected to render decisions in accordance with justice and equity. In arbitration cases, where the engineer is the sole arbitrator under the contract, and in other cases where he is chosen to act as an arbitrator to decide on the principles of equity and justice, he works under higher laws than the decrees and ordinances of local and national authorities, and he cannot be too much impressed with the authority vested in him to judge between his fellow men. With such responsibility laid on his mind, he must think in larger terms than are contained in mathematical text books, and in the rules for performing work. He becomes a judge of men, and is required to make allowance for their weaknesses. He must give to each his due according to reason and the law of God to man, and he must be fair and impartial in deciding conflicting claims. These are fundamentals of equity and are binding on one who is appointed to decide in accordance with equity. He must recognize that exact calculations may be misleading because of uncertainty in the data on which they are based. He must also get the truth from his witnesses, remembering that a witness may be led into telling a technical falsehood, when he is endeavoring to tell the whole truth and nothing but the truth, and this is especially apt to be the case when under examination by a shrewd lawyer whose object is not to elicit the truth, but to make the evidence point to some predetermined conclusion. In such cases the arbitrator has only himself to lean upon, and cannot escape making his own decision, when dealing with questions which are clouded with lengthy testimony, and so involved that their only solution is in beginning with fundamental facts and principles, and working upward from them to determine what of the testimony is relevant and material.

As nothing can exist without a foundation, so there are always fundamentals to be considered in deciding any questions. Some things are fundamentally right, and others are fundamentally wrong. A knowledge and observance of fundamentals leads to correct conclusions. A neglect of fundamentals leaves the engineer up in the air, without a foundation to support him. Logical reasoning brings one into acquaintance with fundamentals. Mathematical computations, accurate workmanship, and strict observance of rules of procedure, only lead one astray if they are not founded on right fundamentals. Starting right, and keeping the right in view one does not make mistakes, although his capacity may limit the amount of his accomplishment. With right fundamentals this amount is determined by his equipment of professional knowledge and skill. Do not understand that I decry professional knowledge, without which the highest rounds of the professional ladder cannot be reached. Nevertheless, professional attainments are but as chaff in the wind, if they are not applied with due regard to fundamentals which reason and common sense make known to us.

My address thus far is written from the view-point of one who may be said to be looking backward over his experience, and is now considering the application of fundamentals to a practice in which large questions are considered, and the factors entering into these questions are supplied by others.

Young men who listen to me may say in their minds, "What has this to do with me? I am only an assistant; I work under orders, doing what I am told to do. I make calculations and plans and do instrumental work as directed by others." This is all very well; you are engaged as you ought to be, and my advice to study and utilize fundamentals is of more importance to you than to older men who have not so much ahead of them. You cannot get away from the necessity of being fundamentally right, nor can you shift the responsibility for being so to your employers. You only have a better opportunity of preparing for future success by applying fundamentals to your present work. The principle applies to details fully as well as to aggregates, and the habit acquired of doing each thing because there is a fundamental reason for it, is the best preparation for judging the work of other men which you will be called to do in coming years.

It is the early years of an engineer's practice that determine his usefulness in later years. It is not only necessary for you, while working under instruction, to prepare the foundation for the successful conduct of affairs when you come into control of your own time, and must direct the energy of others; but as different foundations are required for different structures, it is imperative that you should choose those fundamentals which will serve as a foundation for the kind of man you wish to make of yourself. Right here is perhaps the turning point in the career of many a man. Choose to be the right kind, form your ideal, and work to it as if it were a plan traced on drawing paper. Do not think all that is required of you is to hew to the line, and that there are no materials for the engineer to work with except those enumerated, and whose qualities are set forth in engineering text books. Do not let your ideal fall short of the highest type of manhood,—that kind which makes an impression on fellow men, and helps them to higher manhood. Study human nature, remembering that your dealings with men are more important than your use of inanimate materials, and that as your practice as an engineer advances you will be called to weigh and to value men, and to be morally responsible for their successes as well as for your own. Perfect yourselves in technical training in the specialty which engages your services, but do not give up your life to it. Take a broad view of the work of other specialists because as an independent engineer—which you must hope some day to become—you will have to judge of their work and incorporate it with your own. It is an acknowledged fact that a complete knowledge of one specialty is an education for judging other specialties. The competent specialist finds remunerative employment at times when others seek it in vain, and this fitness for doing particular things should be acquired while young, as a sort of professional insurance. When you have secured this insurance, learn all you can of other specialties, because, with increase in rank, you will have to include them in your practice. You will then have use for the acoustical engineer and the illuminating engineer, and for sundry other kinds of engineers. Such men are most useful, and they will probably discard the restrictive titles they have adopted, when they in turn reach the stage of employing specialists in other lines. In the meantime, it is a pity that they are unwilling to be called civil, or mechanical, or electrical, or mining engineers. Only yesterday a young man told me he was going to be an engineer. He said he was specializing in electricity in a technical school, the name of which I do not mention. I did not learn just what limited education he aspired to, and I guessed he was qualifying himself for a lineman,—a commendable occupation, which should give him a good living,—and that he will probably blossom out with a card designating himself as a "wire-pulling engineer." That will be altogether proper under a system permitting the assumption of titles at will.

Among the engineers composing this society and whose title is guaranteed by their membership certificate, there are specialists in all lines covered by our profession, many of them having attained eminence in particular directions. Still, it is scarcely possible that any of our members are personally qualified in all branches of the profession, and while giving the best of service in our own specialties, we should never fail to protect our clients by securing the assistance of competent specialties in work we control which is of a character different from that to which we have given our own attention. This is co-operation. We constantly speak of our pride in the profession, and of our desire to elevate it, and to build up a proper spirit among its members, and there is no way to accomplish this end which is better and more proper than to employ our fellow engineers and to combine their best work with our own. An engineer cannot be all things to all men, and he attains his greatest value as he adds to his own strength the strength of others.

The highest position to which an engineer may be elevated is to be in charge of interests and operations of such magnitude that his detail work must all be done by his assistants, including specialists of different kinds. In this position his duty is to choose, for the different classes of work, assistants who are qualified for the duties he requires of them, to see that their work is properly done, and to generally exercise such supervision as will result in efficiency. He then becomes a real "efficiency engineer," and may have in his staff "efficiency specialists," who will count and value the movements of the legs and arms of the workmen who do the real work.

There was never a time when so much was expected of engineers as at present. The profession has never before received the recognition it now enjoys. Never before have there been so many and such great enterprises in which controlling positions must be given to engineers, for the reason that the success of these enterprises depends on applying the forces of nature for the use of man. There are engineers capable of filling these places who are recognized, and are appointed to them. The qualification for such a place is a special knowledge and experience in line with the enterprise, and what is not less important, a knowledge of fundamental principles which will enable the engineer to correctly solve questions involving the application of natural laws, and the use of, and right relations, between men.

If there be any merit in this discourse, I dedicate it to our younger members. Young men need foundations, old men need roofs. Young men must build upward, old men whose capital is experience, may follow the example of the architects of modern buildings, who seem to have their fundamentals at the top, and to build downward, suspending their columns from the interior frame which the engineers have provided. The young engineer who appreciates that he must be the architect of his own fortune may make a great and noble structure of it if he builds on the right fundamentals.

Examples are more effective than demonstrations with words, and it is healthful and helpful to study the life and work of such engineers as excite our respect and admiration. All men have faults, but if we look for the good in them, we find inspiration and instruction to aid us in striving for the ideal we have adopted, and if we study enough examples we may construct a composite ideal combining the admirable qualities we have observed in many men, and if in addition we have selected our examples from among those who have passed from us into another world, we have no occasion even to remember such faults as they may have possessed. Study our list of members and you find scores of names among the living and dead, whose personal qualities and professional attainments ennoble the profession. It is not fitting in this connection to mention names of living members, and I hesitate to select names from amongst our honored dead, lest in my imperfect knowledge of their virtues, I may not arrange them in their order of merit, but as I write this there comes to me the memory of Pope, Parkhurst, Dun, Lassig, and many others to whom I have been indebted for their influence and example. I call to your attention another example by quoting from recent Chicago newspapers. A telegram from Gary, Ind., reads:

> "When Harry N. Atwood passed over the sand dunes near Miller, Ind., he gave the natives a view of modern aviation. They were well acquainted with antiquated aviation, for Octave Chanute, the father of aviation, made his first flights in that locality in 1896. Work in the steel mills was practically suspended in Gary, and scores of locomotives and the steel company's whistles heralded the approach and passing of the aviator."

Another newspaper in an editorial, referring to the great aviation meet in Chicago in August of this year, states:

> "There probably will not be a contestant in the events who will not turn his thoughts back to the days only a few years in the past when Octave Chanute, a Chicago engineer, was conducting aeroplane experiments on the shore of Lake Michigan, only a few miles from Grant Park. Every man who guides a machine in its flight will be willing to acknowledge that to Chanute more than to any other man belongs the credit of making flying possible.
>
> "The debt to the Chicago experimenter has been acknowledged by most successful aviators. In every machine which will start upward from Grant Park at the aviation meet there doubtless can be found substantial evidence of the constructive genius of Octave Chanute. He lived long enough to see the practical application of principles which he had formulated.
>
> "Fifteen years ago aeroplanes were tested in the sand dunes region of northern Indiana. The experimenters had the wings and the tail of the bird-like machines, but could apply no motive power excepting that which a fair running start down a hill could generate. The 'landing' invariably was a wet one, for the end of the journey was the lake. There probably would be no meeting of aviators one week from Saturday if Octave Chanute and a few other men had not been willing to face ridicule in the effort to learn the secret of the mastery of the air."

Octave Chanute was one of the best friends this society ever had, and likewise, a friend and encourager to each of our members who enjoyed his personal acquaintance. He was a persistent seeker of fundamentals, and I advise all who have not done so, to read his memoir, published by this society, and to profit by his example. Indeed, I think a condition should be attached to the award of the Chanute prizes, that the recipient should read this memoir.

We hear much in these days about a broader education for engineers. The subject is frequently mentioned amongst those who, in the course of their practice, have learned the necessity for breadth of vision and action, and I think practicing engineers will generally agree with me that this lack of breadth is a real weakness in our present make-up. The universities are considering the subject with a view to providing a remedy for this weakness, but the professors and graduates sometimes make the mistake of assuming that engineers are made at the universities. The education of an engineer is neither begun nor ended in the schools; the university cannot make an engineer; it cannot even give him an engineering education. It can only partially equip him for his journey through life. He must find his own way across the rivers and over the mountains, learning how to overcome the dangers which confront him; to make use of the favorable features of topography, and to find pleasant camping places as he travels. The engineer's education is never completed. This would mean that he knows and obeys all of the laws of God and of man, which is reducing the proposition to an absurdity. The very fact that he must be a learner all through his life is the chief charm of his occupation. What he accomplishes on his journey and where he finally ends, must depend on himself. He will be a successful engineer if he leaves a record of useful work, and if his own life and the lives of others which come in contact with his own, are made happier and better.

He must be a man among men of all occupations, making himself a useful citizen and an agreeable member of the society in his community, increasing his opportunities for helping others, and by making his own self and attainments known to them, enlarging his circle of professional clients. He should recognize his obligation to the commonwealth and should respond to its calls for duty. Such calls for advice and assistance frequently go begging without response, losing at the same time chances for securing recognition of the profession. Because engineers build railways and power plants and other utilities, there is no reason why they should not take their places as good citizens, interested in, and assisting in, every good work intended to better the conditions of their race.

All of this he will accomplish, if he strives for the right ideal, and builds on the proper fundamentals.

* * * * * * * * * * * *

I finished, yesterday evening, the manuscript which has been read to you, and as I had been informed that my address should occupy forty minutes of your time, I asked my sentimental assistant, whom I have dubbed, "poetical engineer," to listen, and time me, while I read the address. It seemed to me good reading and absorbed my attention, and when I finished reading, and looked up, behold, the said P. E. was asleep, and the time was not recorded. Judging from effect, I concluded the address was long enough, and that my hearers would think it lasted forty minutes, plus.

The P. E. then, with a desire to soothe my wounded feelings, innocently inquired if there was not something in the address about fundamentals. This was as much as I could stand, and I thought the incident was closed, but when I arose this morning, the faithful P. E., with a lovely blush, handed me the following, ascribed to "The Engineers."

I read it to you, that I may place the compliment where it belongs, and will only comment, that I will enjoy a sweet revenge if it puts you to sleep:

THE ENGINEERS.

From the hills and chasms and quarries,
    Echoing from shore to shore;
From Atlantic to Pacific,
    O'er Niag'ra's awful roar;

Piercing through the heart of mountains,
    Swiftly traversing the plain,
E'er reverberating, rising, comes the
    Well deserved refrain:

Wonder working men of power—
    Mighty men of brain and heart;
Bridling every force of nature
    With their magic hidden art!

Digging to the fundamentals,
    Dredging far beneath the stream,
Where the deep gives up her secrets,
    Under science's piercing gleam:

Belting continent with iron,
    Reining steam to do their will,
Holding the electric current;
    Naught withstands their hand and drill.

Point and line and angle scanning,
    To the fraction of a degree;
Men dependable and truthful,
    Men of well-prov'n accuracy!

Men of brawn and men of wisdom,
    Of exactness and of wit;
Men to guide and help their fellows—
    Most pre-eminently fit!

Men to touch the heart and motive
With precision just as fine,
As when building roads and bridges,
They keep ever to the line.

Bowing to the Master Workman,
Following ever in his trend,
Which to loftiest heights of science
Will a sacred glory lend.

Men of soul and deep devotion,
Prophets of the Nation's weal,
Men, who all their aspirations
With enduring monuments seal.

Men who strike the fundamentals
In life's heart, as in earth's breast;
Men who higher climb, and higher,
Reaching ever toward the best.

Discussion.

President Chamberlain: It has seemed to be the custom, among the past presidents of this society, after passing through the presidency to consider that their duties consisted simply in attending the meetings of the Board of Direction, and it has been only on rare occasions that we have had the pleasure of listening to papers by our past presidents. There has been one notable exception; the gentleman who has addressed us this evening is a past president and talked to us something less than two years ago upon his trip to the Orient. I am delighted this evening to see so large an attendance to greet our distinguished fellow member. I know we all feel that we have listened to an exceptional address and that this is an exceptional occasion. In opening the discussion, then, I feel that I would not be doing justice to the occasion if I did not take advantage of the presence of some of our older members. We shall all be glad to hear from Mr. Cooley, a past president, who is with us this evening.

Lyman E. Cooley, M. W. S. E.: The paper that you have heard is so admirable and so highly polished, like a waxed floor, that if a man treads unwarily on it he is liable to slip up.

I think I agree with all that the author has said, and only regret that he has put a limit of forty minutes on his talk, because he might save us all the trouble of attempting to say anything more. I hestitate to make any remarks in connection with a paper that has been so well considered, because it has been my invariable experience that I could think of a much better speech when I was going home after the meeting than I could make at the time.

In my somewhat younger days I have had occasion to make addresses at universities, and my theme has frequently been upon the subject of engineering education. There has been an extraordinary growth in engineering education all over this country until, in several of our great universities—Michigan, Illinois, Wisconsin—the tail is wagging the dog. Contrary to the opinion of many educators, I have not deprecated such a movement, because it seemed to me that the business of universities is to teach men how to think. Whether they follow the technical profession or not, that is the best education which teaches men to reason, to know why things are so, rather than to base their ideas upon authority, which is too much the case in these scholastic courses. So I would like to see the engineering education, broad and thorough as you please to make it, become more universal than it is as a system of education and preparation for life. However, education does not make engineers, and the speaker has put that very wisely, I think. It is a matter of aptitude, just like any other art. An engineer, in a sense, is born; but no amount of education can spoil him and any amount of education will be useful to him and increase his breadth and capacity.

I think I agree with the reasoning of the author, if not quite in accord with his opening statement. He said engineers were much like other men, with which I disagree. They are much different from other men. I think his paper clearly proves by precept and example that this is so. The engineer is not like the business man. I have never met a business man that could not sell me something for more than it was worth. No engineer could do that. The engineer is not like the lawyer. The lawyer is often able to make the judge and jury believe something that is wrong. It is impossible for the engineer to do so. The engineer is not like the politician. We find too often in the emergencies that beset public affairs, that republics are run on the appearance of things and not on things as they are. The engineer has to be right, as the author remarks, or he is punished by the natural law, from which there is no appeal. And however he may have started in early life, by long practice through the years, it becomes natural to think on the equity side of things, to be right at all times, and not take advantage of other people. So I believe that engineering is not only the proper preparation for life, in the sense in which the author used it, but conduces to Christian ideals, as illustrated by our distinguished member. Engineering has a higher place than any other profession.

There are some points of view in regard to the profession, however, which were foreign, I judge, to the purpose of the author. I think of the engineer in the original sense, according to the original significance of the word, the man who brings things to pass. The engineer, fundamentally, is a creator. What the engineer created was called an engine. It might be any sort of device for a specific purpose. By transfer of meaning, not uncommon, in the growth of language, the word came to apply to the fellow who operated the engine, and later to the surveyors of quantities, who obtain the data for the engineer, until with the growth of the profession it has come to be applied to everybody who has any relation to engineering whatever, and they are giving themselves all sorts of titles, which seems to be deprecated by the author.

This brings me to a thought which the author only squinted at a little, and that is, engineers are too often not the real creators, but hired men and adjusters. The creative thought is born of others. The things which the engineers are to do in applying the forces and materials of nature are projected and determined by others, and the engineers, in the majority of cases, come in to set things right and work out details.

This brings me to still another thought, that engineers do not take a proper part in public affairs. I was at one time before an important committee of the United States Senate, upon which sat a very honorable senator, who was recognized by his colleagues as an engineer, and took great pride in the title. He sought my acquaintance, and I learned that in early life he had been a rodman on a railway survey in Kansas. That is the only case I know of where a man who called himself an engineer ever sat in the United States Senate. I do not know of any engineer ever sitting in the House of Representatives at Washington, and I have never heard of one in the state legislature except in the "third house." Go abroad, however, and you find engineers in all the branches of government, holding responsible positions—where they ought to be—participating in the affairs of the nation. In these days of conservation, public development, and ownership—all that sort of thing—they are needed and should take an active interest in shaping affairs; they should not keep themselves in cold storage, guarded in a vault away from the world, and then go out and bitterly complain that they are not appreciated and properly compensated—do not get the world's rewards.

Gentlemen, I do not want to go into this subject too far, because Illinois has a reputation for strange doings. If a man refers to anything that might be by any possibility construed as politics, he is liable to censure. So I will leave it.

I want to refer for a moment to the name of one gentleman that the author has spoken of: I wish to add my personal testimony in regard to Mr. Octave Chanute. I have known Mr. Chanute, it seems to me, all my life and he got the impression in some way that I was another. He came to me in 1893 and invited me to sit on a jury on aviation at the World's Fair, which invitation I felt obliged to decline, on the ground that I was engaged in some enterprises of my own, at which the public looked askance, and to add aviation to my list might interfere with my usefulness. But I did pick out for him the particular sand-dunes upon which he made his experiments in Indiana, in 1896. I was familiar with that region from personal exploration. When he had concluded his experiments we talked them over, or rather he told me about them, and said that the problem was solved. The mechanics of the matter had been fully worked out and it was only a question of producing engines of a weight of six or eight pounds per horse power in place of the then limit of twelve to fourteen pounds; with such power we could fly, provided human beings developed the necessary aptitude. Mr. Chanute could not follow the matter further, owing to limited means, and he proposed to make a record of his work and leave the application to others. I regard Mr. Chanute as one of the great engineering minds in the proper use of the word, and he is receiving the recognition he is entitled to.

Another great man that has not been referred to was Mr. E. S. Chesbrough,—one of the charter members and pioneers of this society, and City Engineer from 1854 to 1878, when Chicago was lifted out of the swamp, obtained the lead, and became preëminent in the great valley. Our present engineering estate is largely due to Mr. Chesbrough. Our sewer system, our lake tunnels, and other provisions were novel in their day, and he acquired an international reputation. About 1878 the sewerage question was a pressing one, even in that day. I remember asking him at that time about the future solution of the matter, and raised the question of the ship canal. He replied that if this city should ever reach a million inhabitants that solution would be ideal, but from his experience of the growth of cities and his knowledge of Chicago he did not feel justified in designing public works on the theory that we would reach a million inhabitants within a reasonable time. That may seem strange from a man of his foresight, as we take the rear view of events. In 1885 I had occasion to draft a report upon the subject matter for the Citizens' Association. I devoted a paragraph to the growth of population, and predicted one million people in 1890, in order to justify our financial strength. The wise men who directed the destinies of the association, and who admitted that they were leading citizens of Chicago, asked me to strike that paragraph out, as it would discredit the report; they said that nobody in Chicago would believe we were to have a million people in 1890, they did not believe it themselves. As a matter of fact, we had something over a million inhabitants.

Mr. E. S. Chesbrough I want to add to the list of eminent engineers mentioned in the paper. I want to stand for him as one of the greatest the society has ever had among its members.

I wish to revert for a moment to the subject of engineering education, and relate an incident. In 1883 there appeared in my office in St. Louis, with several elaborate letters of introduction, a Japanese student and a graduate of the Imperial College at Tokio. It developed that I was to look after his course of post-graduate education in the United States for the next two years. I asked him why he had come to the United States as the curriculum at the Imperial College was as thorough as in our own technical schools. He replied that he knew this, but he had come over in order to acquire

"American aptitude." He filled four or five engagements in the course of his two years, leaving one for another, as soon as he felt that he had mastered the same. He practiced his profession in Japan for some twenty years, and in 1908 he called at my office in Chicago on his return from an investigation of technical education in Europe, and told me about his career. He stated that after some twenty years of field service, "he had been promoted to a professorship" in the Imperial College. I leave this incident to those who can read as they run.

I will not pursue the subject further. As I remarked at the beginning, I shall probably think of many instructive and eloquent things, as I go home, which I might have said, but will leave them to others here, who are well equipped and quite able to say them.

C. F. Loweth, M. W. S. E.: The hour is late and Mr. Bates has covered the ground so fully and splendidly that little more can be said. The fundamentals which he, more than any others, lays stress upon are those which make for manly character. This is a quality at least as essential to the success of an engineer as to that of a business man in any other vocation. Those fundamentals which make a successful business man are likewise essential to the making of a successful engineer, and in addition the engineer must have many others, for he must not only be a skillful engineer but at the same time a man of good business knowledge and ability.

Many of the fundamentals the author has referred to are not to be gotten out of books; they must be learned from observation and experience; sometimes, for some, out of hard experience and many failures and disappointments.

One fundamental for success which comes to mind at this time is that quality called tact. Tact is a subtle quality, and hard to define; it is more or less a natural talent with some, while others can only with difficulty acquire a minimum of it. We see all about us men who are successful largely because of their tactfulness, and also many other men, of splendid qualities and attainments, who fall short of a large measure of success because they apparently have little or no consideration for the different temperaments, viewpoints, and feelings of those with whom they associate.

Another fundamental is patience—a much neglected one in these strenuous times. Doubtless most of us can recall instances of mortifying failure because the supply of patience was insufficient for the occasion. This fundamental is two fold in its nature, and there is needed not only the exercise of patience in a man's relations to those with whom he associates, but also a similar attitude of mind towards the tasks which make up his vocation. This last is a quality somewhat akin to painstaking.

Success in business, as an engineer or otherwise, is not infrequently due as much, and sometimes more, to painstaking care than to other qualities; a successful design may at times be due more to a designer's painstaking than to his abundant knowledge; and the success of a piece of construction is sometimes more largely dependant upon the painstaking care of the men in charge and the workmen than upon their skill.

Albert Scheible, M. W. S. E.: The excellent address of our honored ex-president has dealt so much on the value of precedent and of character-building, and both he and Mr. Cooley have referred to the value of the college training, that I would ask Mr. Bates what he thinks of a tendency that has grown during the last several years in our technical colleges, namely, their setting an example in the way of serving two masters. Nearly all of us, I think, have been familiar with young men whose career has been spoiled by their indulging in side lines and looking to them for earnings instead of confining themselves to working for their regular employers. We certainly would expect our technical colleges, our engineering schools, to set an example in that respect; and yet, with the notable exception of the University of Illinois, we find that in a large share of our engineering schools—I would not say all—there are a number of able men in each place who are paid by the institution for only part of their work. For the rest of their remuneration they have to look to commercial interests. In other words, instead of being free to devote all of their time and all of the facilities which the laboratories provide to the instruction purposes for which both are provided, they are expected to cater to commercial interests and to draw money from them for tests in order to secure the balance of the pay that is due them. This so far as I know, is in no case an exorbitant figure by the time they get the total of both. It seems to me that we have there an example that is hardly in line with the high standard of fundamentals that Mr. Bates has presented.

Mr. Bates: Referring to the remarks of Mr. Scheible, I get my cue from Mr. Loweth; I think it will require a little tact to answer that question. I am free to say, first of all, that it is not fundamentally right for any institution of learning to employ a professor and require him to go outside to make a living. They ought to pay him well. I have a great many friends among the engineering professors and I often think that those men are giving their lives as much as a minister or a missionary does, for the good of their fellowmen; that they might do better professionally outside than they can where they are employed.

As to a professor taking any practice, I do not care to express any definite opinion on that. There is a great deal to be said on both sides. In favor of that, the professor improves as a professor, and is able in many ways to do more for the students. Then, again, if the professor has time, sometimes people need him so much that it would not seem to be right to hinder them from obtaining his services. When we come to a question on university practice, my opinion is not good for much. I am not a university man except by brevet.

FOUNDATION AND SEWER WORK.—COSTS AND COMMENTS.

Victor Windett, M. W. S. E.

Presented June 7, 1911.

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INTRODUCTION.

The writer's experience as an engineer in charge of construction, and as a contractor for a number of years, has led him to believe that to a considerable extent neither engineers nor contractors have as intelligent an idea of the cost of doing work as they have of the average rates of payment for the work done.

An important duty of an engineer is to assist his principal in negotiating for low contract prices. But the interests of employer and engineer are best served by the engineer, advising when the limit is reached below which an over anxious contractor should not lower his price. During such negotiations the contractor in his eagerness to secure the prospective work, is apt to yield to an unsafe extent to the urging of the contractee. It is no more to the interest of the owner to have a contractor take a losing contract, than for the contractor himself.

In order to keep a close daily watch of the labor costs of contracts which he has been executing, the writer evolved a simple method of recording and digesting the daily expense, which has stood the test of several years use. It is a practice among contractors to load on to the timekeeper as many duties as possible. Hence his cost-recording work must be simple and not involve much extra labor. There are many systems of recording such information, running from one extreme of noting the minutes and seconds used for each minute operation to the other of seeing if the bank account at the end of the job showed a surplus after paying all bills.

In presenting the methods of cost-keeping and the results obtained by its use, the writer recognizes the fact that other methods may be more suitable for some different conditions. But the methods of this paper have been found to be simple, efficient, elastic and easily understood.

The costs recorded in this paper and the original figures upon which they are based may appear to be too minutely detailed. The tabulations are so summarized as to present totals and averages to those who desire a broad general knowledge of costs, without going through a mass of details. But for the man who watches the daily costs of a piece of work which he is carrying on in a multitude of separate operations, the detailed figures may be of use for comparison.

As to *motion study,* that is, analyzing and timing each individual motion made in performing a certain work, the writer tried it on scraper work where slip and wheeled scrapers were used. The haul was short and the work light, that is, the soil was moist sand. The note of discord which prevented the experiment being more than a slight success was the facts that the teamsters were indifferent and disinclined to exert themselves; their pay was high, and as men were scarce and hard to secure they kept shifting around from one employer to another as the fancy seized them.

The writer's opinion is that contractors for construction works such as are discussed in this paper generally employ such a shifting class of men, and the plants used are of so transient a nature as not to be as susceptible of elaborate systems of recording and analyzing costs, and standardizing manual operations, as may be the case in some factories where there is seldom a change in the employees, and the daily routine is well known.

There is a belief, somewhat prevalent among many engineers and contractors, that analyzed cost data of earth excavation and kindred operations are not of much value, except to the one having personal knowledge of the work to which they pertain. Hence such data are apt to mislead. This may be a fair criticism if the information is not complete both as to physical conditions and operations and as to costs of labor and materials. Yet in making estimates of cost of proposed work, or bidding for construction contracts, such available records must be referred to or else some better substitute must be available.

The substitute on which they risk their reputation or money and time is the so-called *practical experience or judgment*, and is something more or less real, but highly cherished nevertheless. In its ultimate analysis this *judgment* is apt to be a more or less uncoordinated collection of memories, vivid according to whether they refer to highly-profitable or bad-losing jobs. Those pieces of work showing a moderately small profit, accompanied with less anxiety or excitement in their prosecution, do not have so large an influence in forming such a judgment, and their impress on the memory is not so marked. Such an instance was the building by a very rapid and skillful bricklayer of catch basins in a day in a sub-contract at $10.00 each, all materials furnished him ready for use. This single instance has had much to do in the making out of a number of bids. As compared with this is the detailed record of every labor item given herein, of 212 catch basins costing $13.60 apiece.

Nevertheless, many contractors are skillful in estimating current market prices for work, as the following instances, and the writer's experience, show.

Contract *A*, 62 items bid upon in New Orleans
Bidder *W*, $714,549.25
Bidder *X*, 715,521.80
A difference of 972.55 or 1/7 of 1%

Contract *B*, at Waukegan, Illinois
Bidder *Y*, $89.870.20
Bidder *Z*, 89,992.69
A difference of 122.49 or 1/7 of 1%

Contract *C*, in Chicago
Bidder *N*, $31,956.55
Bidder *O*, 32,341.72
A difference of 385.17 or 1 1-5%

Method of Cost Keeping.

The method of cost-recording on which this paper is based has been used by the writer for a number of years on many kinds of construction. It is flexible, fitting widely different classes of work. It is simple, requiring but little work in the field on the part of the timekeeper, and is not complicated with many blank forms or reports.

The results given in the following pages are based on the construction of upwards of 60,000 ft. of sewers of diameters of 6 ft. and less, the excavation of 200,000 cu. yds. of sand, clay, and alluvium, laying over 6,000,000 brick, placing of 40,000 cu. yds. of concrete, driving over 20,000 piles, and other materials in large quantities.

The tabulated records cover such a diversity of conditions and materials as to make them of more value than generalized averages deduced from them. For in making an estimate of cost, generalizations are not of an equal value to detailed records of similar constructions. The limitations of an engineering society paper preclude the inclusion of more than is needed to explain methods of recording costs, and show the nature of the data from which the generalized figures are derived.

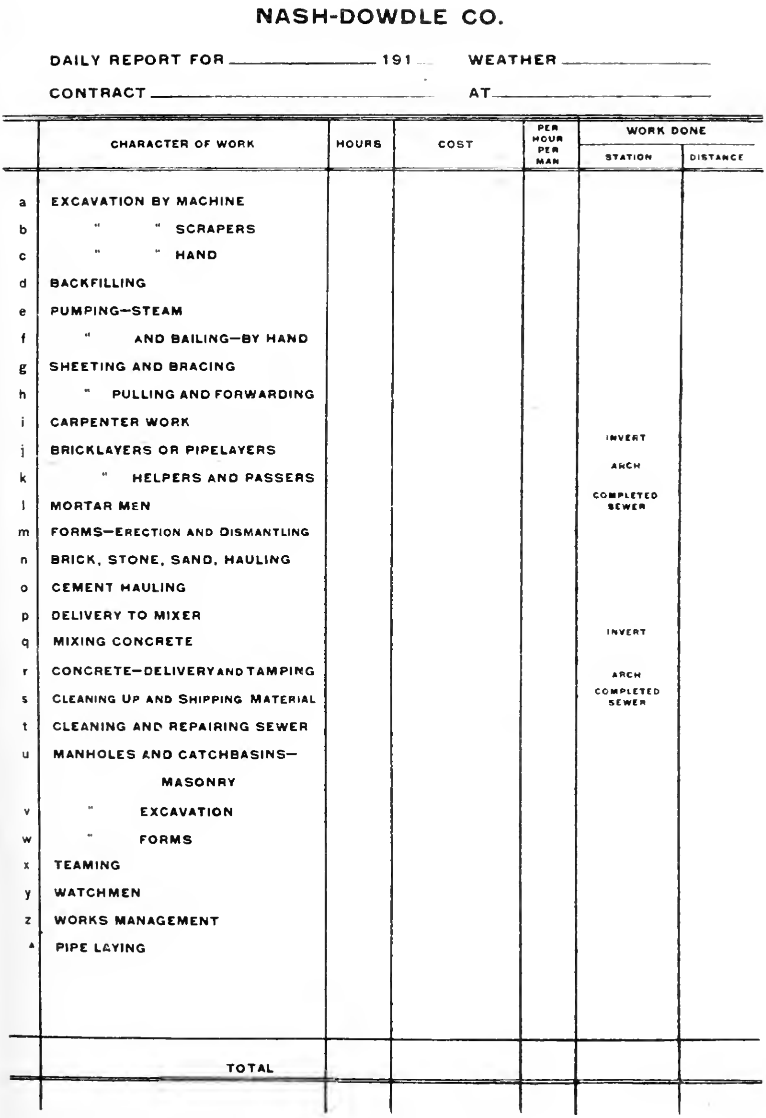
All operations are recorded in hours of labor as well as costs in dollars and cents. As the average hourly wage is given, it is possible to compare the work reported in this paper with other pieces of work where different rates of wages may prevail.

The method used in keeping the records on which this paper is based is as follows: The various items of a distributed labor cost are each designated by a letter such as *A* for excavation, *B* for pumping, *C* for carpenter work, etc., as shown on Diagram Sheet 1.

The timekeeper has a general oversight all day of the men employed. He makes a formal entry in his time book, at the beginning and close of the morning and the afternoon and at special times to suit the putting at work or laying off of men. The making of a pencil dot in each corner of the time-book space for the day was altered by substituting a letter indicative of the man's work as shown on Sheet No. 1.

Towards the close of the day, ten or fifteen minutes will suffice for the timekeeper to call off from his book the number of hours, rate of pay, and characteristic letter for the men at work. These are written down columns headed by the letter. With a little practice the multiplication of the hours and rates is made mentally, and the product set down as fast as the timekeeper calls off the "time"; these columns being added, the daily reports are made out. The method of penciling these figures is shown on Sheet 1.

The following daily report sheet shows the classification of the work, the corresponding labor in hours and its cost in dollars, the average hourly wage for each item, and a column for the physical measurements of the work. The size of the sheet is such as to fold twice to fit an ordinary stamped envelope.



NASH-DOWDLE CO.

DAILY REPORT FOR ________________ 191__ WEATHER ________________

CONTRACT ________________________ AT ________________

	CHARACTER OF WORK	HOURS	COST	PER HOUR PER MAN	WORK DONE	
					STATION	DISTANCE
a	EXCAVATION BY MACHINE					
b	" " SCRAPERS					
c	" " HAND					
d	BACKFILLING					
e	PUMPING—STEAM					
f	" AND BAILING—BY HAND					
g	SHEETING AND BRACING					
h	" PULLING AND FORWARDING					
i	CARPENTER WORK					
j	BRICKLAYERS OR PIPELAYERS				INVERT	
k	" HELPERS AND PASSERS				ARCH	
l	MORTAR MEN				COMPLETED SEWER	
m	FORMS—ERECTION AND DISMANTLING					
n	BRICK, STONE, SAND, HAULING					
o	CEMENT HAULING					
p	DELIVERY TO MIXER					
q	MIXING CONCRETE				INVERT	
r	CONCRETE—DELIVERY AND TAMPING				ARCH	
s	CLEANING UP AND SHIPPING MATERIAL				COMPLETED SEWER	
t	CLEANING AND REPAIRING SEWER					
u	MANHOLES AND CATCHBASINS—MASONRY					
v	" EXCAVATION					
w	" FORMS					
x	TEAMING					
y	WATCHMEN					
z	WORKS MANAGEMENT					
A	PIPE LAYING					
	TOTAL					

Daily Report Sheet.

In the *field* office sheets are kept as shown in Diagram 2, in which the data on the daily reports are copied in columns, so as to permit adding up week by week. From these sheets are made weekly reports of costs and quantities of work, Sheet 4.

When carefully watched, the daily report of hourly average wage for each occupation becomes a most valuable indicator of the costs. This is especially so in "open shop" work. There is a constant tendency, as a piece of contract work goes on, for the average rate of wages to rise. To overcome this is one of the strongest incentives to push work to a rapid completion. In order to keep a close watch on the daily cost of the various operations during the execution of a contract, it is necessary to have a more detailed division of labor made than is the case when using the data for other purposes.

Towards the close of the Gary sewer work in 1907, a certain foreman having 80 men under him had finished the work, except backfilling. He had a number of high-priced skilled Irish and Italian trench men and a large number of Slavonians who could not speak English. The average hourly wages of his gang was $0.23 per man. Having received orders to do his backfilling with a smaller gang, he kept the men who could understand English. The following day the average wage had risen to $0.294. The daily report brought him to realize what he had done, and his expense dropped the next day to $0.245 per man per hour.

A more noteworthy example of the value of such a report was had in comparing the work done in the Gary district under similar conditions of soil, climate, ground water, character of work, and time. Daily reports were carefully watched on work requiring 101,315 hours of labor costing $28,314.75 at an average hourly wage of $0.279 per man. Other work from one to two miles distant required 30,151½ hours of labor costing $10,069.75, or $0.336 per man per hour. In this latter work the foreman was an able, experienced trench man, and resourceful in management of work. He ignored the daily reports and devoted his efforts to pushing the work. He had a great aversion to the Slavonian labor, preferring English-speaking men. But his costs per unit of work were high. Had this policy been pursued on the larger work, the difference in cost would have been, for the 101,315 hours of labor, at $0.057 per hour, $5774.98, an increase of 20.4%.

The nationalities represented by the men employed in the works whose records are given here are native born Americans, British, Italians, Austrians, Hungarians, and men from southeastern Europe. In spite of a certain prejudice against the latter, it must be recognized that they are as hard and willing workers as men of the first named countries. An instance of this was the excavation of solid hard blast furnace slag at the rate of 1.8 cu. yds. per man per day, by Slavonians, as compared with the clay and cinder excavation of the hammer shop above mentioned, at the rate of 2.0 cu. yds. per man per day by Irishmen and Italians.

In sewer work the operations naturally fall under three headings, viz: trenching, masonry, general labor. Trenching includes excavation, sheeting and bracing, pumping, and backfilling.

In sewer work the distribution of expense of the various operations of construction is given in Table No. 1, which is based on 55,000 lineal feet of work.

TABLE 1.

PROPORTIONAL DIVISION OF EXPENSES OF CONSTRUCTION.

	Concrete Sewers.	Brick Sewers.	Pipe Sewers.
Excavation labor	12.1%	20.7%	22.3%
Sheeting and bracing labor	7.0	10.0	7.2
Backfilling labor	4.9	3.3	6.0
Pumping labor	.5	2.3	10.0
Total trenching labor	24.5	36.3	45.5
Masonry labor	25.0	20.0	4.9
Operating superintendence	4.5	5.2	4.6
Total labor	54.0	61.5	55.0
Materials and supplies	41.6	30.0	29.6
Office expense	4.4	8.5	15.4
Totals	100.0	100.0	100.0

At the time when the invert is placed in the concrete or brick sewers, the work is 57% and 65% respectively, completed. In the case of the pipe sewers when the pipe is in position, 69% of the work is done.

There is a tradition to the effect that when cost of labor is equal to the sum of the cost of materials and supplies, plus the profit, a bid thus made should show a fair profit. On the basis of the data given in Table No. 1, the following figures are obtained:

TABLE 2.

PROBABLE PERCENTAGE OF PROFIT.

	Concrete Sewers.	Brick Sewers.	Pipe Sewers.
Labor	50.0%	55.0%	50.0%
Materials	35.6	22.5	20.6
Profits	14.4	22.5	29.4
Total	100.0	100.0	100.0

The rate of profit which this supposition shows is not a fixed percentage, and in its amount is somewhat accidental. An inspection of the tabulated costs of pile driving, fire bricklaying, or foundation concrete, shows that this supposed relationship does not hold at all as the cost of the materials largely exceeds that of labor, which is contrary to the assumption of this theory.

Excavation.

Earth handling in engineering construction involves a number of operations. In this paper the word excavation is taken to mean the removal or digging of the soil only. Other collateral operations, such as backfilling, pumping of water, sheeting and bracing, are discussed under their respective titles.

In hand digging a contractor will find it advantageous to furnish shovels to his men. Just before the men go to work they can take a shovel from the tool box, the timekeeper standing by so as to note the men to whom shovels are given. At night he can check the return of the tools in like manner. This will prevent the clipping off of an inch and a half or two inches from the cutting edge of the shovel, which is a common trick of men so as to lighten their day's work.

In damp sand trenches to a depth of about 6 ft , the "bottom" man is supplemented by a "bank" man to cast the spoil back from the edge of the bank. For deeper trenches a "scaffold" man is put in at about 5 ft. below the surface, and additional ones at each 4½ to 5 ft. in depth. In pipe sewers the pipelayer excavates the final foot and a half to two feet and throws the spoil back on the last pipe laid.

In compact damp sand trenches, such as are found above the plane of the standing ground water or in trenches drained by well-points, the average angle of inclination of the sides of the trench has been found to be 8° 48′ from the vertical where skeleton sheeting and bracing is used. But these occasional braces are placed not so much from necessity of holding up the bank as a matter of safety against an accidental caving which would bury the men in the trench. Banks have been cut by scraper and stood without any bracing for 10 to 12 days at an average angle of 19° 26′ from the vertical.

The steepest angle measured in sand trenches were for hand work 3° 35′ and for scraper work 8° 8′ from the vertical.

In the compact Indiana dune sand the slope at which standing water was found showed a rise of 6.3 ft. in 335 ft., starting at the surface of a river.

Table No. 3 gives the cost of labor of digging or excavation and depositing the earth in a spoil bank beside the trench, and does not include other trenching operations, such as pumping of ground-water, and sheeting and bracing.

The quantity dug per man is based on the total number of men in the digging-gang, including scaffoldmen and bank-

TABLE 3.

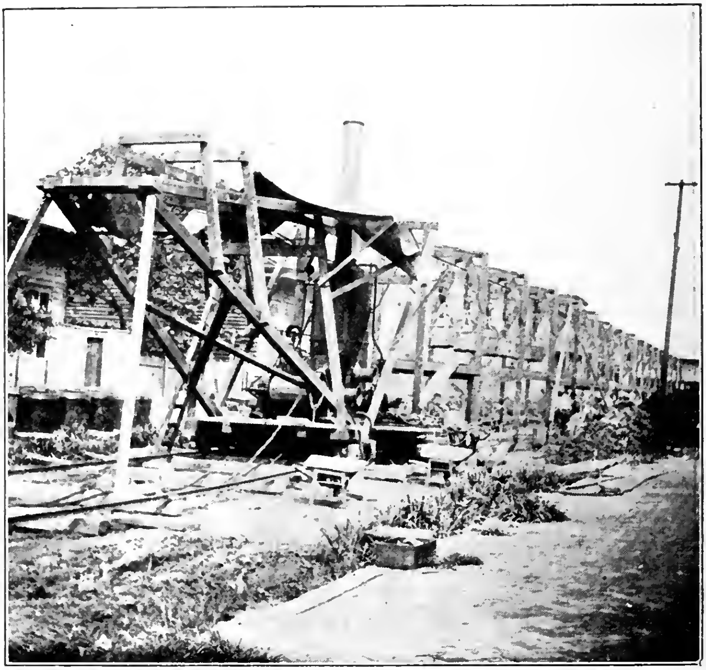
COST OF EXCAVATION LABOR.

Size of Sewer	Soil	Kind of Pumping	Average Depth Ft.	Day's Work Per Man, Cu. Yds.	Hour's Wages	Cost Per Cu. Yd.			Cost Per Lin. Ft. Labor
						Hand Labor	Total Labor	Total Labor and Materials	
24x36 in.	Wet Clay	Hand	2.5	7.7	$0.23	$0.27	$0.27		$0.125
22x32 in.	Sand	None	8.0	12.5	0.19	0.14	0.14	$0.15	0.56
8 in. dia.	Sand	None	5.4	15.3	0.22	0.13	0.13		0.076
10 in. dia.	Sand	None	6.2	8.8	0.36	0.37	0.37		0.173
12 in. dia.	Sand	None	5.0	20.0	0.22	0.12	0.12		0.106
12 in. dia.	Sand	None	10.4	9.3	0.23	0.16	0.16		0.31
12 in. dia.	Sand	T. P.	7.8	6.1	0.23	0.34	0.34		0.26
12 in. dia.	Sand	T. P.	10.0	4.0	0.225	0.50	0.50		0.53
12 in. dia.	Sand	Points	10.0	8.3	0.269	0.30	0.30		0.38
12 in. dia.	Sand	Points	6.7	11.2	0.282	0.25	0.25		0.204
12 in. dia.	Sand	Points	8.2	11.9	0.265	0.25	0.25		0.22
15 in. dia.	Sand	Points	9.0	9.0	0.267	0.28	0.28		0.32
18 in. dia.	Sand	T. P.	9.1	7.6	0.268	0.37	0.37	0.39	1.10
18 in. dia.	Sand	Points	10.4	5.7	0.290	0.35	0.35	0.37	0.447
20 in. dia.	Muck&Sand	T. P.	15.0	2.9	0.200	0.61	0.25		1.300
24 in. dia.	Sand	T. P.	6.4	3.4	0.207	0.55	0.55		0.55
24 in. dia.	Sand	T. P.	8.3	4.2	0.210	0.44	0.44		1.01
24 in. dia.	Sand	T. P.	14.7	2.7	0.214	0.72	0.49		1.66
24 in. dia.	Sand	Points	9.8	6.7	0.272	0.34	0.34	0.36	0.59
30 in. dia.	Sand	T. P.	4.8	2.4	0.261	0.98	0.48		1.84
36 in. dia.	Sand	T. P.	6.0	7.2	0.217	0.27	0.24	0.30	0.81
36 in. dia	Sand	T. P.	7.1	4.4	0.238	0.54		0.57	0.73
36 in. dia.	Sand	T. P.	9.0	4.9	0.210	0.76			1.05
36 in. dia.	Sand	Points	11.4	3.8	0.270	0.65	0.52	0.64	1.28
42 in. dia.	Sand	T. P.	12.0	2.9	0.27	0.42	0.61		1.68
42 in. dia.	Sand	T. P.	17.2	6.5	0.227	0.32	1.23		0.74
48 in. dia.	Sand	T. P.	14.0	4.3	0.246	0.52	0.30		1.04
54 in. dia.	Sand	T. P.	12.7	4.3	0.290	0.19	0.43		1.19
54 in. dia.	Sand	T. P.	19.4	1.9	0.235	1.11	0.34		3.24
54 in. dia.	Sand	T. P.	21.9	3.1	0.247	0.71	0.20		2.15
57 in. dia.	Clay	None	12.2	4.3	0.413	0.86	0.10		0.363
60 in. dia.	Sand	T. P.	16.7	3.7	0.21	0.50	0.29		2.79
60 in. dia.	Sand	T. P.	19.3	2.8	0.18	0.55	0.33		2.18
63 in. dia.	Clay	None	13.7	2.8	0.41		0.117		0.55
66 in. dia.	Clay	None	16.7	3.1	0.44	1.29	0.127		0.71
72 in. dia.	Sand	T. P.	12.8	4.1	0.26	0.43	0.23		1.53
72 in. dia.	Sand	T. P.	15.2	3.4	0.21	0.55	0.30		2.14
72 in. dia.	Sand	T. P.	16.0	3.1	0.277	0.75	0.17		2.42
72 in. dia.	Sand	T. P.	19.7		0.26	0.30	0.47		3.04
Austin Mach.	Clay	None	4.0	2.0	0.406	0.78	0.78		
Austin Mach.	Clay	None	8.5					0.274	

men. The items given in the total labor column is the average of all of the methods used for the particular piece of work. In the column headed *Pumping* the word *Hand* indicates hand pumping, *T. P.* refers to trench pumping or pumping direct from the trench, and *Point* means pumping by well-points before the water enters the trench.

The working day was nine hours long, except that scrapers were worked ten hours.

One class of excavating machines for trench work does not eliminate hand-digging but does away with scaffold and bank men and backfilling labor. Such are the Carson trench machine, Carson Lidgerwood cableway, Moore trench machine, and Moore surface trench and pipe laying machine. In all of these machines the trench men dig by hand and fill buckets which are transported back of the masonry or pipe-work of the sewer, and backfill at once by dumping in the trench. All of these machines are useful, and are conducive to rapid work. For general trench work the cableway is superior to the other machines, especially where the work crosses street car tracks. The expense of the machine including thereby the items of depreciation, repairs, and operation are usually far below the cost

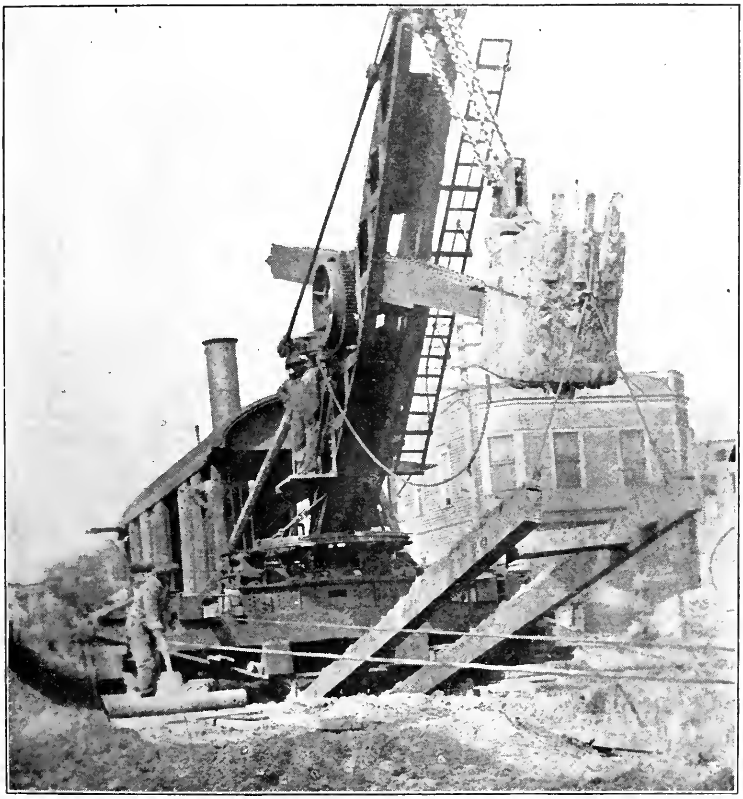


Carson Trench Machine.

of scaffold and bank men and backfilling which the machine displaces.

The other class of machines used by the writer are machines doing away with hand-digging, such as orange-peel derricks, steam shovels and the Austin trench machine.

For trenching in clay a steam shovel is an ecomonical and rapid working machine. For such work it is carried on heavy timbers on 8 in. diameter by 4 ft. long hard maple rollers over the trench. The railway trucks are taken off while the shovel is working.



Steel Stringers to Hold Sheeting When Digging With Steam Shovel.

The trench must be sheeted and braced except in the short space where the dipper is working. The bracing gang have at hand necessary sheeting and bracing, and are also busy in shaping up the bottom to fit the contour of the masonry. As soon as the dipper enters the trench for its last stroke a whistle is sounded and the bracers hold themselves in readiness to act.

When the upward stroke of the shovel is half completed, the men spring into the section of ten to twelve feet of trench and quickly place a couple of pairs of stringers and braces, behind which sheeting is lowered into place by men on the banks. This work calls for great speed, as sometimes a fraction of a minute is sufficient time for a cave-in of the unbraced trench sides.

In some cases the trench is braced, in the portion being excavated, by two stiff steel beams with a cross brace at each end. The rear end of these beams is carried by chains hung from the frame of the shovel, and the forward end rests on the ground. These beams are used at a depth of 2 ft. or so below the ground surface. In moving these beams ahead the forward chain attached to them is caught over the dipper and pulled ahead by a forward stroke of the dipper.

In sandy soil sheeting must be driven ahead of the shovel.

The shovel roughly shapes the bottom of the trench, and the work is completed by a small gang of men working under the body of the machine. They cast the earth ahead so as to enable the shovel to remove it.

In heavy work, and for trenches which are not too wide to be spanned by the frame carrying the machine, the shovel is unsurpassed for speed of work. A depth of 22 ft. has been dug in this way.

In New Orleans, using a half-yard dipper 25-ton steam shovel over a trench 14 ft. wide and 12 ft. deep, 855 lin. ft. of trench, or 5,320 cu. yds. of earth, were dug in 55 hours of work. The soil was alluvial river mud in an old partly drained cypress swamp, consisting of one-third cypress roots and stumps. The sheeting for the trench sides had been driven ahead of the shovel and the bracing was carried on simultaneously with the digging of the trench. As the sheeting and bracing were a part of the permanent construction of the canal, a temporary set of stringers and braces was used for the operation of the shovel. The labor-cost of this trenching, including the bracing, was $0.08 per cu. yd. To this expense should be added the expense of moving the shovel on and off the job, which amounted to $0.04 additional, making the total cost equal to 12c per cu. yd.

The cost of moving a shovel under its own steam on rails from a railroad-siding to the site of the work in Chicago, for a haul of something over a mile, was at the rate of $0.06½ per lin. ft.

In New Orleans a 25-ton shovel was moved in 5 days 13,000 ft.

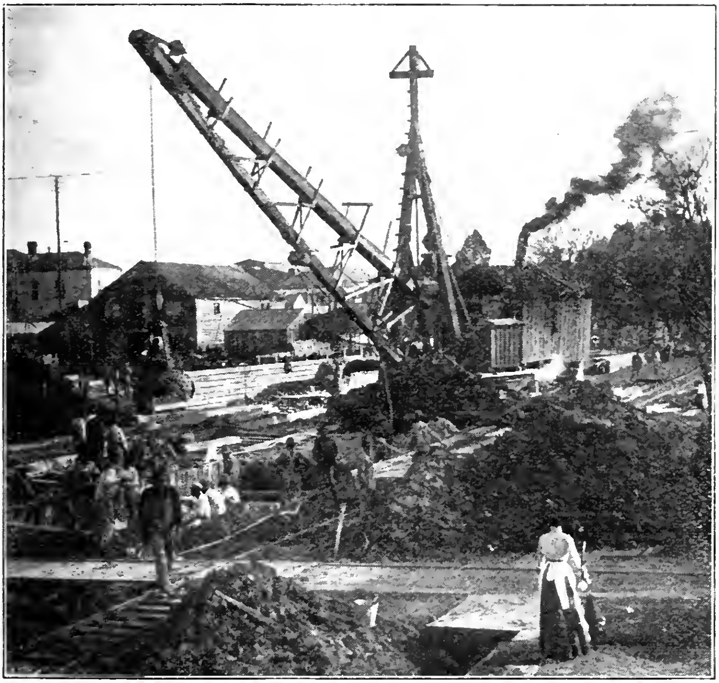
Removing and resetting crane	$100.00
Labor, of men and teams, coal, water	175.00
Cutting electric wires and general expense	75.00
Total	$350.00

Cost per foot, $0.02¾. Progress 260 ft. per hour.

A team was used to drag, ahead into position for use again, the pieces of track over which the shovel had moved.

Another machine which the author has used with success is a traveling swinging derrick, known as the Kearns swinging derrick, operating an orange-peel bucket.

This machine moves on solid ground ahead of the trench. With a three-quarter yard bucket, operated by a power swinging 56 ft. boom, the best day's work done was 920 cu. yds. excavated in ten hours. This was in a trench sheeted by pile driving ahead of the digging. The braces were placed 8 ft. centers, as the depth of the digging required, in a trench 14 ft. wide by 12 ft. deep. The spoil in part was loaded on three yard cars and in part dumped on the ground 50 ft. away. The soil was alluvial river deposit.



Orange Peel Excavator for Trench Work, ¾-yard Capacity.

In excavating for the Plaquemine, La., lock approach there was used a three yard orange-peel bucket hung from a boom 85 ft. long and loading on flat cars on a trestle 20 ft. above the working level. This boom was swung by gravity. The earth was wet Mississippi River alluvium. This bucket was changed in favor of a two yard bucket because the larger bucket would overload the machine. The three yard bucket, would, at times, take loads of approximately 4½ cu. yds. heaped up over the bull wheel, which strained the timber framework.

The digger discharged its load onto flat cars on a trestle adjacent to the work. The average haul for a loaded train was approximately 400 ft. Two light engines would handle three cars. Unloading was done by a Lidgerwood plow working between stakes on the sides of the car. The three yard bucket would place a load on the cars in 55 seconds. With delays due to all causes the average output of the machine was 1320 cu. yds in a day of 10 hours. The labor cost was $0.19 per cu. yd. of earth dug, including operating, maintenance, transportation of spoil, and unloading. The maintenance of the trestle was a considerable item.

3½-yard Orange Peel Excavator With 85-ft. Boom.

For trench work a ¾ cu. yd. orange-peel bucket is about as large as can be economically used, because a larger bucket requires too much room, and would also require the bracing to be spaced farther apart than 8 ft. centers; this would necessitate timbers too heavy to be handled easily by the trenching gang.

An Austin trench machine of the Municipal Engineering Co. was used at Clearing, Illinois, in a clay soil for a 4 ft. width of trench. This machine runs on broad wheels ahead of the trench. It cuts and excavates by small plows fastened on bars, the ends of which are carried by link belt chains running over sprocket wheels. These plows carry the earth up a slide and discharge it on a belt conveyor which deposits the earth in a spoil bank parallel to the trench. A certain amount of the spoil falls back into the trench so that it was found necessary to dig some 6 in. deeper than the depth required for the sewer. The quantity of earth excavated, as claimed by the operator in his reports to his company, exceeded the net quantity actually required by 5%. The quantities of excavation given below are *net* quantities corresponding to the depth of the masonry.

TABLE 4.

EXCAVATION BY AUSTIN TRENCH MACHINE.

Size of trench, 8 ft. 5 in. deep, 4 ft. wide, 2,974 ft. long.

Volume of excavation	3745 cu. yds.
Time of digging	72 hrs. 30 min.
Delays chargeable to machine	39 hrs. 0 min.
Delays chargeable to contractor	42 hrs. 40 min.
Total time of work	154 hrs. 10 min.
Time of excavation per day	9 hrs.
Rate of digging time	372 lin. ft. or 468 cu. yds.
Rate of total time	173 lin. ft. or 220 cu. yds.
Max. day's work including 1 hr. 20 min. delay	455 lin. ft. or 549 cu. yds.

The delays chargeable to the machine include all mechanical delays, shifting deadmen, caving of bank onto gutter, etc. The delays chargeable to the contractor were those incidental to sheeting and bracing of the trench, and inability of the bricklayers working in so narrow a trench to work fast enough to keep up with the machine.

This machine required the following force of men: 1 Operator at $5.00 per day; 1 Engineer and Fireman, $3.50; 1 Team for Coal and Water, $5.50 per day; 4 Laborers for runways and placing deadmen logs, at $2.50 each. The rental was $10.00 per day, together with a charge of 10c per cu. yd. of earth dug. About half a ton of coal per day was burned. This daily expense was equal to $0.274 per cu. yd. of effective depth of the trench.

Usually in hand-excavated trenches, scaffold and bank men are needed only for a depth greater than that from which the bottom man can throw earth onto the surface at a convenient distance from the trench. Hence the output per man of the excavating force decreases as the depth of the digging increases, on account of the additional men engaged in rehandling the earth passed up on to scaffolds.

Trenches in sand of a considerable depth dug by slip scrapers, an orange-peel or drag scraper are usually widened to such an extent that the earth dug in the final hand bottoming can be cast up from the sheeted lower part of the trench in to the wider part thus provided, thereby saving additional bank men, which otherwise would be needed to cast this spoil above the original surface of the ground.

Table 5 is given as an example of very cheap hand labor, and a large output of work per man.

TABLE 5.

EXCAVATION OF A SHALLOW DRY (MERELY DAMP) SAND TRENCH.

Time, November, 1909.
Place, Buffalo Ave., S. of 124th St., Hegewisch, Ill.
Length, 275 ft.; Depth, 5 ft.; Width, 4 ft. 6 in.; 229.3 cu. yds.

Labor:

Trenchmen	107 hrs.	$23.55	$0.22 per hr.	$0.0994 per cu. yd.
Bankmen	27 hrs.	5.40	0.20 per hr.	0.0227 per cu. yd.
Total men........	134 hrs.	28.95	0.216 per hr.	0.1221 per cu. yd.

Each Trenchman, per 9 hr. day, 20 cu. yds.

Blast Furnace Slag Excavation.

Blast furnace slag in a liquid state is usually poured from ladles and forms a bank of solid hard stratified rock. The strata vary in thickness, usually up to four to six inches or more. The bond between the strata is not strong. But on account of the irregularity of lines of fracture and its sharp angularity when broken by the action of picks, bars, or wedges it is an exceedingly difficult and tenacious material to excavate by hand labor or by steam shovel.

Four cases of slag excavation are given below, as lettered, *A B C D*.

Case *A*. The slag was cast up on the brim of the trench by the men who dug it. This was hard slag in a solid mass.

Case *B*. About half of the slag was cast up in a spoil bank by scaffold men and bank men, and about half (the lower portion) was loaded by the diggers into one cubic yard buckets and emptied into cars by a locomotive crane. The spoil bank of the first portion of the digging was rehandled in part and loaded on to cars also. This slag was a solid mass of hard slag.

Case *C*. The mass excavated consisted of broken rubble masonry, loose slag, earth, brick, and debris.

Case *D*. Loose slag, earth, and a small amount of solid hard slag.

TABLE 6.

Blast Furnace Slag Excavation.

Kind of Slag	Depth Ft.	Length Ft.	Breadth Ft.	Work Per Man Per 9-hr. Day	Rate of Wages	Cost Per Cu. Yd.	Rate of Wages	Cost Per Cu. Yd.
A. Hard Mass	2.9		11.0	3.6	$0.15	$0.367	$0.25	$0.61
B. Hard Mass	13.0	70	13.0	1.8	0.169	.0894	0.25	1.34
C. Hard Loose	6.0	60	12.0	1.8	0.125	.596	0.25	1.19
D. Hard Loose	6.0	925	3.0	4.1	0.125	0.274	0.25	0.55

In the table above the cost of excavation has been recalculated on a basis of $0.25 wages per man per hour to make the expense comparable with the work in sand and clay of the other tables.

When slag is not disposed of by the blast furnace man in a solid mass, it is granulated by pouring it into a tank, or pit of water. This granulated slag is then used for making or grading land. On account of the cementitious qualities of the slag in this form, it hardens into a dense tough mass which is as hard to excavate as the hot-poured slag.

In the following table are presented figures for excavation, being a summary of the preceding discussion. The writer would express his preference for sufficiently elaborated and numerous statements of individual prices of work rather than for average figures. The day's work is taken as nine hours long, except for slip scrapers in which case ten hours constituted a day's work.

In New Orleans the soil is alluvial. Near the Mississippi River it is quite sandy. That is, grains of exceedingly fine sand are intimately mixed with the usual constituents of soil which make a light earth easily dug. Further back from the river it takes on a more clayey character, making a dense, sticky, tough, elastic earth called *gumbo*. The gumbo earth is made more difficult of excavation by being saturated with water and the presence of cypress roots, stumps, and logs in great quantities. Stumps many feet in diameter have been cut out of trench, sometimes only to find another equally as large immediately below it. In Table No. 8 costs of labor in New Orleans are given, based on the excavation of upwards of 100,000 cu. yds. of earth. The laborers were negroes, whose rate of pay per hour in the light trenches varied from $0.175 to $0.20, and in the deep trenches from $0.20 to $0.27½. Pumping was done by gasoline-driven centrifugal pumps and by hand pumps.

TABLE 7.

EXCAVATION COSTS VICINITY OF CHICAGO.

Kind of Work	Soil	Pumping	Depth Ft.	Day's Output Cu. Yds.	Rate of Pay Per Hour	Cost Per Cu. Yd.	Remarks
Hand work	Sand	None	5.0	20.0	$0.216	$0.122	One case
Hand work	Sand	None	7.0	13.2	0.182	0.184	Average
Hand work	Sand	Well Points	9.4	8.1	0.273	0.35	Average
Hand work	Sand	Trench-pump'g	9.0	4.53	0.225	0.553	Average
Hand work	Sand	Trench-pump'g	16.4	3.65	0.24	0.56	Average
Hand work	Clay	Hand-pump'g	2.5	7.7	0.23	0.27	Average
Hand work	Clay	None	11.7	2.4	0.42	0.92	Average
Hand work	Alluvium	None	7.5	5.5	0.17	0.29	Average
Hand work	Alluvium	None	7.5	11.4	0.175	0.14	Average
Hand work	Alluvium	None	9.0	6.2	0.174	0.26	One case
Hand work	Alluvium	None	11.0	3.7	0.175	0.43	One case
Slip scraper	Sand	None	6.0	39.5		0.14	Average
Orange peel	Sand	None	24.0			0.104	Average
Orange peel	Alluvium	None	12.0	450.0		0.060	One case
Steam shovel	Alluvium	None	14.0	918.0		0.035	One case
Steam shovel	Sand	None	10.0			0.325	One case
Steam shovel	Clay	None	20.0			0.068	One case
Austin Mach	Clay	None	8.5	468.0		0.274	One case

TABLE 8.

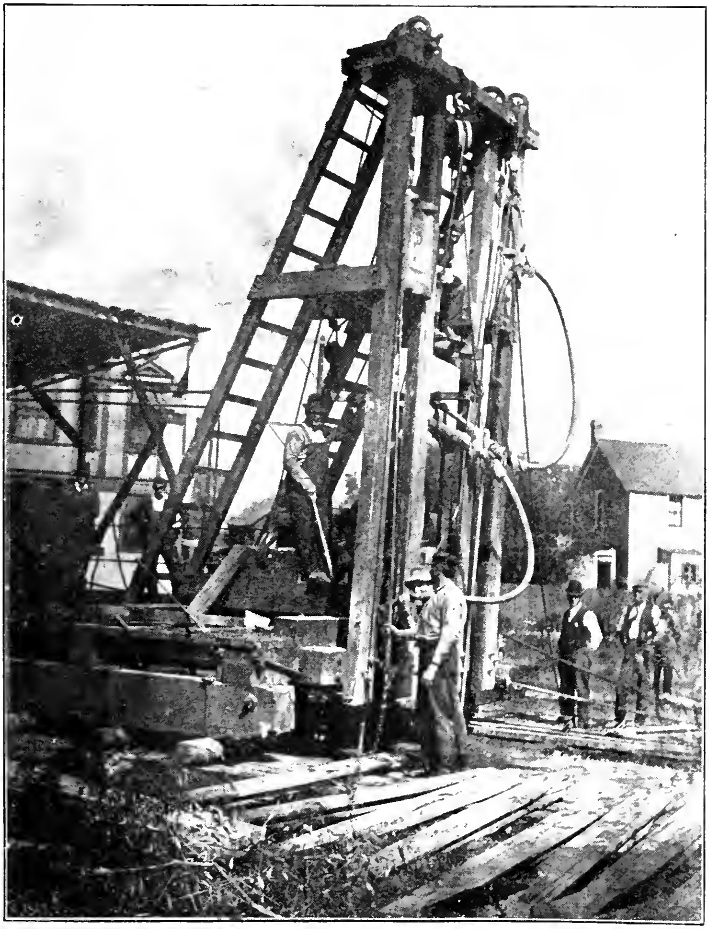
EXCAVATION LABOR—NEW ORLEANS AND LOCALITY.

	Depth in Ft.	Day's Work Per Man Cu. Yds. or per Mach.	Rate of Pay Per Hour	Soil		Rank	Cost Per Cu. Yd.
Hand labor..........	7.8	4.2	$0.175	Gumbo	Downtown	2	$0.277
Hand labor..........	7.7	10.8	0.175	Sandy	Uptown	1	0.145
Hand labor..........	9.0	6.2	0.175	Gumbo	Downtown	3	0.255
Hand labor..........	11.0	3.7	0.175	Gumbo	Downtown	4	0.433
Carson Trench Mch..	8.0				Downtown	5	0.44
Carson Trench Mch..	18.0				Downtown	6	1.073
Carson Lidgerwood Cableway	18-23				Downtown	7	0.68
Moore Trench Mch.	15-20			Gumbo	Downtown	8	0.461
Moore Pipe Laying Mach.	9.5			Sandy	Downtown	9	0.392
Steam Shovel........	12.0	885		Gumbo	Uptown	10	0.120
Orange Peel.........	20	1320		Sandy	Plaquemine	12	0.19
			0.23				

SHEETING AND BRACING OF TRENCHES.

Sheeting a trench by hand is best done by using sheeting of 2 in. thickness, 8 in. to 10 in. in width and 12 or 14 ft. long.

Larger sizes are inconveniently heavy and hard to handle. The upper end is trimmed to 6 in. width to admit of using a cast steel or wrought iron cap to protect the end of the sheeting when being driven. The lower end is sharpened like a chisel with the bevel towards the center of the trench.



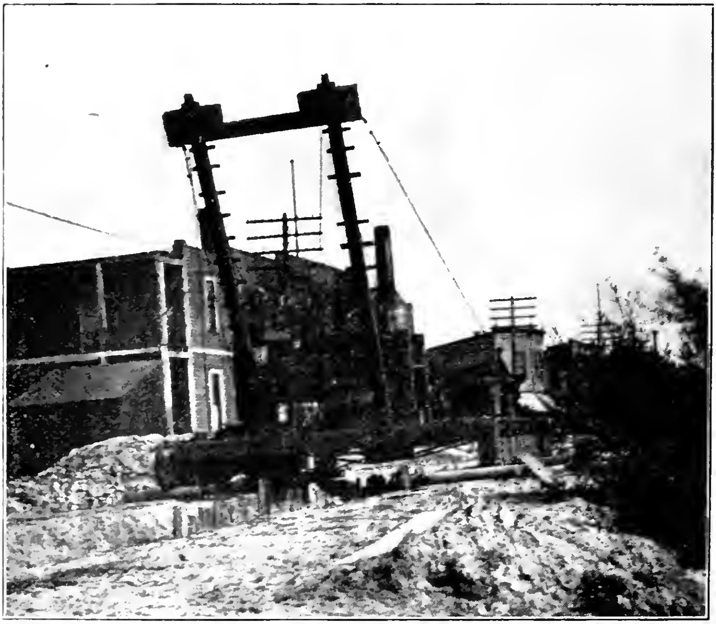
Trench Sheeting Pile Driver With Double Leads.

Mauls for hand driving are made of live oak, hickory, or iron wood, with hickory handles. The striking face of the maul is 5 in. diameter and at the eye for the handle the diameter is 6 in. to 7 in. Wrought iron rings $\frac{3}{8}$ in. by $1\frac{1}{2}$ in. are driven on the ends and fastened by oak wedges or $\frac{1}{4}$ in. boat spikes.

In sand trenches, sheeting should always be driven by means of a water jet to assist the maulers. The economy in labor and lumber is so great as to make this imperative, when it is possible to use it. Water pressure should be about 100 lb. per sq. in. The point of the jet should be ¾ in. diameter.

The jet pump is advantageously placed a day's work ahead of the sheeting, and a pipe run along the trench from the end of which are run two lines of hose to operate a jet for each side of the trench.

The sheeting gang consists of a bottom man to guide the sheeting, and three maulers. Ahead of them are two men jetting and placing sheeting, assisted by a team and attendants to carry sheeting ahead as fast as it is pulled from position behind the masonry.



Portable Machine for Pulling Sheeting.

For steam-shovel work, as at Hegewisch, in sand a light pile-driver was used with two hammers of 1200 lb. each. The sheeting used was triple lap. The center piece was 2 in. by 10 in. by 14 ft. with two 1 in. by 4 in. by 12 ft. side pieces, made up for a 2 in. tongue and groove. In a nine-hour day 240 pieces of sheeting could be driven, easily.

The sheeting was pulled, after the trench was partly backfilled, by a double drum, double cylinder, engine on a platform somewhat similar to the pile driver but substituting a hinged *A* frame for the leads. A ½ in. chain and ⅝ in. cable were used for the line. This machine would pull sheeting for 100 ft. of trench in a couple of hours. The crew consisted of an engineer, winchman, hooker-on and sheeting-catcher to land the sheeting on the bank within reach of a team.

The wear and tear on the sheeting was very small, as far as the 2 in. by 10 in. pieces were concerned. They were used nine times over and then made into bottoms for catch basins. The 1 in. by 4 in. strips required quite frequent renewal. Possibly it might have been cheaper to use 2 in. lumber instead. This sheeting cost for labor as follows:

Triple Lap—Middle piece 2 in. by 12 in.—14 ft. (some were 12 ft.)
Side pieces 1 in. by 4 in—10 ft.
732 pieces—34.5 ft. B. M. each.
Labor, making up (including pointing & heading to top width of 8 in.)
222 hours—$67.85; wages, $0.31 per hour.
Cost 8.8 hrs.—$2.63 per 1000 ft. B. M.
0.3 hr.—$0.093 each.

For pipe sewers in the case of pumping by well-points, it is not necessary to place the sheeting closer than three or four feet apart and then not within a foot or two of the trench bottom. In fact, it is used as a safeguard to protect the pipe layers against possible caving of the bank, rather than from necessity to maintain the trench sides.

In similar cases for brick sewers where the trench is open longer, the same measure of safety can be secured by giving the trench sides an easier slope together with skeleton sheeting.

Stringers of 4 in. by 10 in., 6 in. by 8 in. and 8 in. by 8 in. are advantageously used, the length of which should be 16 ft. Braces of 6 in. by 8 in. and 8 in. by 8 in. are heavy enough when put 5 ft. 4 in. centers, or three to a stringer length, for depths up to 12 ft. and a width of 12 ft. The calculation of the size necessary is so simple an operation that it should always be done as a guide or check upon the practical judgment of the trench foreman. In alluvial soil 2 in. by 12 in. 14 ft. and 3 in. by 12 in. 24 ft. sheeting was driven by a 2000 lb. drop-hammer pile-driver. No difficulty was experienced in sheeting 150 ft. of trench per day. The lumber was delivered along the line of the trench by teams. The pile-driver crew consisted of nine men.

The cost of preparation of plain ordinary trench sheeting is as follows:

2x8 in.—12 ft. and 14 ft Trench Sheeting.
Pointing and trimming top for driving cap.
467 P'cs. 10900 ft. B. M.
Cost, 105 hrs.=$28.35; wages, $0.27 per hour.
Cost, 9.7 hrs.= 2.58 per 1000 ft. B. M.
Cost, 0.22 hrs.= 0.06 each.

Backfilling.

Backfilling of trenches was done by hand labor, teams with scrapers and with plows, by steam shovels and by orange-peel derricks.

In the case of narrow trenches such as are dug for pipe sewers up to 2 ft. diameter, hand work is cheapest. Men engaged in backfilling can do so within throwing distance of the trench or not over a step or two away. Thus their whole time and energy can be devoted to useful work. Teams necessarily lose much time in going to and from making turns at the ends of each trip. Hand work is easy also as the earth is in a loose and friable condition, suitable for shoveling.

A comparison between these two methods is made in Table 9, under similar conditions of soil, size of trench, and weather, showing the economy of hand work.

TABLE 9.

BACKFILLING OF SAND TRENCHES (NARROW TRENCHES) LABOR.

How filled	By Hand.	By Scraper.
Dia. of sewer	12-in., 15-in., 18-in. dia. pipe.	
Length of trench	1712 ft.	871 ft.
Width of trench	3.0 to 3.5 ft.	
Depth of trench	6.0 to 10.0 ft.	
Volume of, backfill	1447 cu. yd.	751 cu. yd.
Volume of backfill per lin. ft	0.85 cu. yd.	0.66 cu. yd.
Volume per man or team per 9 hr. day	27.0 cu. yd.	50.0 cu. yd.
Cost of work	$121.41	$103.00
Cost per man or team per hr	0.25	0.65
Cost per cu. yd. of backfill	0.084	0.137
Cost per lin. ft. of trench	0.071	0.118
Excess cost by teams		$0.047 or 66.1%

Work done on Houston & Carondelet Aves., Hegewisch, 1909.
Soil, Streets, Weather & Other Conditions Alike; Spoil Leveled on the street.

A general average of all the work, large and small trenches included, showed the following costs:

Scraper labor	$0.056 per cu. yd.
Steam shovel and orange-peel bucket labor	0.078 per cu. yd.
Hand labor	0.086 per cu. yd.

In Table 10, backfilling costs per lineal foot of trench are given. In all of the cases the backfilling was loosely done, and the excess earth either left in place or spread over the ground surface except in the instances given for New Orleans in the last three items. In these cases where the work was in narrow paved business streets the trenches were carefully tamped as backfilling proceeded.

TABLE 10.

Backfill Labor.

Diameter of Sewer	Soil	Trench Depth Ft.	Rate of Pay	Labor Cost Per Lineal Ft.	
				Hours	Cost
8 in.	Sand				
10 in.	Sand	5.0		0.16	0.03
12 in.	Sand	9.0		0.31	0.09
15 in.	Sand	9.0		0.31	0.08
18 in.	Sand	10.0		0.26	0.07
20 in.	Sand	15.0		1.00	0.28
24 in.	Sand	10.5		0.46	0.13
30 in.	Sand	13.6		1.35	0.27
36 in.	Sand	8.2		0.50	0.11
42 in.	Sand	14.6		0.76	0.21
48 in.	Sand	14.3		0.63	0.22
54 in.	Sand	16.5		1.00	0.31
57 in.	Clay	12.2		0.46	0.18
60 in.	Clay	14.0		1.74	0.50
63 in.	Clay	13.7		0.50	0.20
66 in.	Clay	16.7		0.87	0.33
72 in.	Sand	15.1		0.86	0.38
		New Orleans.			
6 in.	Alluvium	6.0	$0.175	0.5	0.07
8 in.	Alluvium	8.0		0.4	0.07
8 in.	Alluvium	10.0		1.0	0.17
10 in.	Alluvium	8.0		1.3	0.19
15 in.	Alluvium	8.0		1.5	0.22

Backfilling of large trenches, especially in heavy soils such as clay, is done cheaper by a light steam shovel. Many such jobs will amply justify the use of an additional shovel for this work in addition to the machine used for digging.

Trench Pumping.

Pumping ground-water from sand trenches will prove to be an expensive operation if ample preparations of thoroughly efficient apparatus is not made and kept ready for use as soon as needed. In trench work there is probably no way in which the expense can be run up so fast as trying to excavate, and lay brick or concrete with an inadequate or insufficient disposal of trench water.

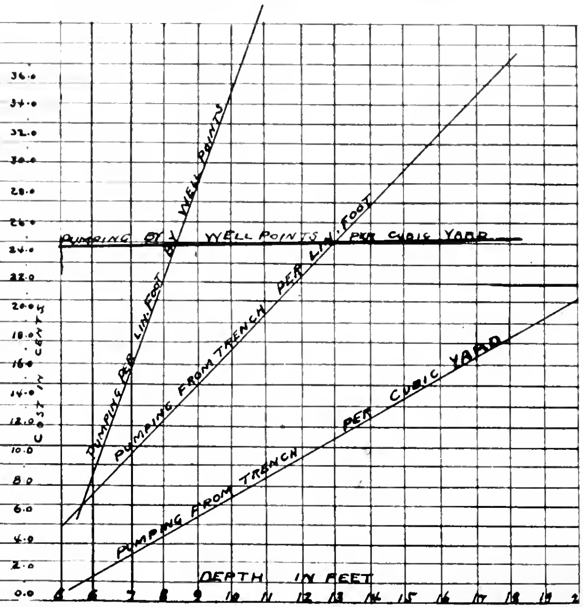
Hand pumping is usually done by means of diaphragm pumps. In order to pump rapidly, such a pump usually takes three men to man it effectively. There are on the market now combinations of the diaphragm pump fitted to a small gasoline engine. These arrangements are so light, cheap, and economical

COST OF PUMPING FROM TRENCH BOTTOM UNIT COSTS

NASH DOWDLE CO
CONTRACTOR

6.
1907-09.

KIND	DIAM	DEPTH FT.	EXCAV'N PER FOOT CU YDS.	COST PER CU. YD. LABOR HOURS	COST PER CU. YD. LABOR COST	COST PER CU. YD. MAT'LS	COST PER CU. YD. TOTAL	COST PER LIN. FOOT LABOR HOURS	COST PER LIN. FOOT LABOR COST	COST PER LIN. FOOT MAT'LS	COST PER LIN. FOOT TOTAL
PIPE	12"	7.5	.7	.09	$ .015	$ .015	$ .03	.05	$ .01	$ .01	$ .02
"	18"	6.8	1.35	.072	.025	NONE	.025	.053	.018	NONE	.018
"	20"	15.0	3.1	.20	067	"	.067	.60	.21	"	21
" AVERAGE		8.6	1.54	.11	.037	.002	.039	.173	.057	.003	.06
BRICK	24"	8.4	1.62	.28	.091	.004	.095	.17	.056	.01	.066
"	30"	13.0	3.50	.45	.141	.041	.182	.12	.038	.153	.191
"	36"	8.7	2.72	.50	.130	.079	.209	.18	.048	.21	258
"	42"	13.0	3.34	.12	.042	.008	.050	.42	.113	.02	.133
"	48"	14.0	5.20	.11	.037	.007	.044	.60	.190	.034	224
"	54"	19.6	9.30	.15	.034	.010	.044	1.40	.310	.088	.398
" AVERAGE		10.1	2.50	.23	.06	.025	.085	.57	.152	.105	.257
CONCRETE	60"	18.0	8.20	.275	.058	.086	.144	2.20	.454	.085	.539
"	72"	14.7	7.43	.079	.02	NO RECORD		.58	.154	NO RECORD	
" AVERAGE		15.3	7.51	.12	.03	.086	.116	.89	.208	.071	.279
	FT LENGTH	SUMMARY									
PIPE	4679	8.6	1.54	.11	.037	.002	.039	.173	.057	.003	0.06
BRICK	16380	10.1	2.50	.23	.06	.025	.085	.570	.152	.105	0.257
CONCRETE	415	15.3	7.51	.12	.03	.086	.116	.890	.208	.071	0.279
AVE.	21464	11.4	362893 CU. YDS.	.18	.049	.023	.072	.56	.15	.091	0.241



in operation that there is little excuse for continuing the practice of hand pumping.

Probably the most usual way of pumping is to pump the water from the trench where it accumulates to a depth sufficient to keep the suction end of the supply hose covered, or runs to a sump in sufficient quantity to prevent the in-flow of air in the suction pipe. The best method of operation is as follows:

The trench is dug to a depth of a foot or more below the water-surface, when the sheeting gang place the sheeting ready for driving. Behind this gang follows the driving gang, using the water-jet process when possible. Excavation is in progress all along by means of leaving an opening in the sheeting by using a short sheeting for each scaffold sand-thrower.

Where the sheeting is fully driven, a bag dam is placed high enough to keep water in this section deep enough for the pump, supplying the jets for driving the sheeting. The excess water flows over the dam into the next section. Here is placed a pump with preferably a 4 in. suction hose fitted with a strainer and foot valve on the lower end. At the lower end of this section is another bag dam. Excavation is in progress in this section. Back of this dam is a section which is being lowered to the final grade for the masonry. This section is usually five or eight feet longer than the length of work to be built by the masons, so as to leave room for bailing water over the dam ahead for the steam pump to handle.

Water is prevented from following the bricklayers by a bag dam in the last masonry invert completed.

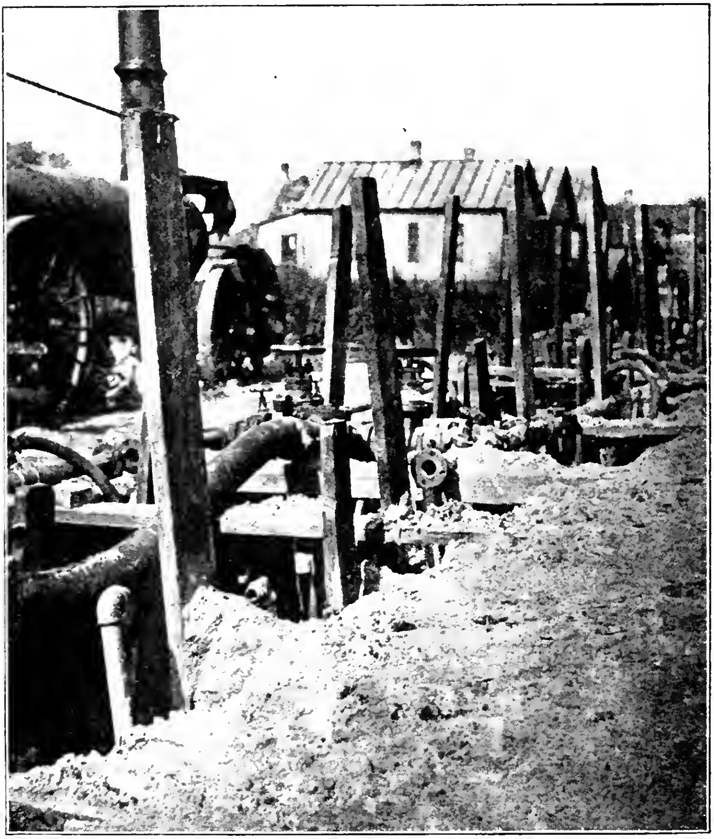
At night time the dams are all lowered or removed, except one a few feet in front of the masonry to catch the sand brought down by the water, and the water is allowed to run down the sewer to the outfall.

One piece of work of a 3 ft. brick sewer built at Pine, Indiana, ran for 4,000 ft. across at right angles to a series of ridges and sloughs. The standing water in these hollows was 2 ft. to 5 ft. deep and stretched for a length of half a mile on each side of the sewer. In addition to handling the water by the method described above, a pioneer body of laborers kept ahead of the trench men throwing up levees across the sloughs, between which the ordinary operations of trenching were conducted. The contract price for this work was exceedingly low, yet a profit was made on the work, despite the extraordinary conditions under which the work was built.

Where the water pumped cannot be discharged at a considerable distance away from the trench by ditches in the ground and when the water is clean enough, it is often possible to carry it back in sectional box flumes or pipes to the last manhole built, and thus let it run down the sewer.

This method of pumping involves the necessity of every one working in water from 3 or 4 in. up to 12 or 15 in. in depth. The consequence is a diminished rate of excavation and increased cost of construction.

Where possible to do so, the most satisfactory method of handling water is to pump it before it enters the trench. In sandy soil this is done by using the *well-point* pumping system. Well-points of 1¼ in. to 1½ in. pipe, with screened inlet opening in the lower 2 ft of the pipe, are driven or *jetted,* so as to draw water from a level below the trench bottom. The customary spacing of the points along each side of the trench is 3 ft. apart. In coarse sand or in gravel a double line of points may be necessary. A satisfactory length of such a system is 300 ft.



Pumping Trench by Well Points.

At Hegewisch a 12 in. sewer was laid for 1300 ft. at a depth of 7 ft. to 8 ft. in a street running along a piece of marsh land where 20 in. of standing water lay on the ground, and within 6 to 10 ft. of the trench. The *point* system kept the water out of the trench satisfactorily.

For small independent pieces of work, like building detached catch basins, half a dozen points can be operated by piping to a hand diaphragm pump.

The expedient of laying a sub-drain under the main sewer, so as to drain a wet trench, is an expensive and slow procedure. The chief difficulties are the choking and filling up of the sub-drain with sand through the joints. The delay required for laying the drain in a wet trench is dangerous, as the running water will carry sand with it, raising the level of the trench center, endangering the sheeting, and necessitating constant removal of the inflowing sand.

In using *points* it is best to draw the water from such a depth that there may be no danger of its rising between the lines of points in the center of the trench. Another advantage of deep pumping is that the possibility of sucking air through the drained-out sand is diminished. The use of points requires constant care and watchfulness to secure perfectly tight joints. Should the pump lose its suction through leaking joints, the results are apt to be disastrous and dangerous. In such cases the water rises rapidly and, entering the trench from the bottom and sides, causes caving banks so rapidly sometimes that the men have difficulty in escaping.

Clay soils are more or less impervious to water. In trenches dug in such soil the open-trench method of pumping direct from the trench bottom is thoroughly practicable practice. The quantity of water being so much less than in sandy soils, makes the problem a lesser one. The matter of moment is the prompt and thorough bracing of the trench, as a wet clay bank is treacherous.

As to the kind of machines to be used, the writer has used centrifugal pumps, duplex reciprocating pumps, the pulsometer type of pumps, and triplex plunger pumps with steam, gasoline and electric power. They are all serviceable machines. The most reliable and confidence-inspiring pumps are the centrifugal and the reciprocating pumps. The latter is positive in its action, every movement being due to a piston always under direct, constant steam pressure. Cleaning out chips, grass, or pebbles from the water end of such a pump is an item of small moment and quickly done. Another advantage is that if the pump happens to be large for the work at any time, it can be run at a speed commensurate with the in-flow of water.

In sandy trenches, when pumping from the trench, the inflowing water generally carries, through sheeting cracks, a large quantity of sand. In such cases this is overcome by caulking the cracks with grass or old spoiled hay, which can be quite cheaply procured. In the Indiana contracts included in this paper, a man was employed steadily in cutting grass on the adjacent land. At Hegewisch fresh-cut grass cost $5.00 per ton load, delivered on the work.

Portable boilers are so much more easily moved from place to place along a trench as to leave no choice between them and any other style of boiler for trench work.

Duplex reciprocating pumps being small, compact, and low in proportion to the work they do, are best mounted upon two small skids sharpened at the ends. A *move* along the trench can be quickly and easily made by pulling the pump by a half dozen men or a team.

An 8 in. direct-connected centrifugal pump was maintained for 417 days in constant service in New Orleans for pumping a section of the sewerage system during construction. While steam was kept at operating pressure continuously, the pumping was intermittent during each 24 hours. The in-flow of water required pumping for a total of 12 hours each day. The labor charge was low, the men being paid $73.50 per month, or 20c per hour, one man on each 12-hour shift tending boiler and pump. The daily cost of operation was as follows:

Coal—Pittsburgh, 3rd Pool coal, 1.275 tons@$2.98 per ton	$ 3.80
Oil—Lubricating and illuminating	0.25
Supplies	0.15
Water tax	0.33
Repairs to pump and boiler	0.93
Depreciation	0.75
Wages	4.80
Total	$11.01
Over-head burden	1.34
Total daily expense	$12.35

The lift of the pump was 19 ft.

Chicago union wages and hours would increase this expense to approximately $20.00 per day.

Trenching.

By *trenching* is meant all of the operations of digging or excavating, sheeting and bracing, pumping, backfilling, and disposing of the surplus earth.

In making estimates or bids it is best to consider the work in question analytically and calculate the costs of the separate operations involved.

For making approximate estimates the labor costs for complete trenching operations are given in Table 11.

TABLE 11.

TRENCHING LABOR COST VICINITY OF CHICAGO.

				Cost Per Cu. Yd.		Cost Per Lin. Ft.		
Size of Sewer	Pumping	Depth	Rate of Wages	Hours	Cost	Hours	Cost	
6 in.	None	5.0	$0.237	0.9	$0.20	0.34	$0.08	
8 in.	None	5.7	0.330	1.0	0.34	0.4	0.14	
10 in.	None	7.0	0.25	1.2	0.37	0.8	0.21	
12 in.	Points	7.0	0.27	2.6	0.71	2.1	0.57	
12 in	Points	10.0	0.27	2.1	0.56	2.6	0.65	
12 in.	Points	11.0	0.25	2.6	0.64	3.1	0.77	
12 in.	None	7.0	0.27	2.0	0.57	1.5	0.32	
12 in.	None	10.5	0.30	0.8	0.22	1.5	0.44	Scrapers used.
15 in.	Points	9.0	0.27	2.1	0.57	2.6	0.65	
18 in.	Points	10.4	0.28	2.4	0.70	3.0	0.87	
18 in.	T. P.	10.0	0.29	2.1	0.81	3.8	1.21	
18 in.	None	6.8	0.25	2.4	0.59	1.5	0.37	
24 in.	T. P.	7.0	0.25	3.6	0.88	4.3	1.08	
24 in.	T. P.	10.0	0.26	2.5	0.70	4.5	1.23	
24 in.	T. P.	12.0	0.28	2.2	0.63	8.0	2.03	
24 in.	None	12.0	0.35	1.7	0.59	2.5	0.90	
24 in.	T. P.	15.0	0.24	3.2	0.78	10.8	2.60	
30 in.	T. P.	11.0	0.26	2.0	0.52	7.1	1.88	
30 in.	T. P.	15.0	0.26	3.2	0.83	12.3	3.20	
36 in.	T. P.	3.6	0.30	5.3	1.55	3.8	1.10	
36 in.	T. P.	7.5	0.24	3.0	0.71	5.9	1.43	
36 in.	T. P.	9.0	0.26	3.3	0.73	8.2	2.25	
36 in.	T. P.	11.4	0.36	2.6	0.93	6.6	2.32	
36 in.	Points	11.0	0.30	1.8	0.51	4.8	1.43	
36 in.	None	7.0	0.38	1.4	0.51	2.0	0.77	
42 in.	T. P.	14.6	0.30	2.1	0.63	7.8	2.28	
48 in.	T.P.	14.0	0.26	2.0	0.52	10.0	2.63	
54 in.	T. P.	12.0	0.26	6.7	1.69	21.5	5.47	R. R. Track
54 in.	T. P.	12.7	0.37	2.1	0.81	6.0	2.23	Steam Shovel
54 in.	T. P.	20.6	0.26	1.6	0.40	16.0	4.08	
57 in.	None	12.2	0.34	0.7	0.23	2.4	0.81	
60 in.	T. P.	18.0	0.26	2.0	0.50	14.5	3.70	
63 in.	None	13.7	0.36	0.7	0.23	3.0	1.08	
66 in.	None	16.7	0.38	0.8	0.28	3.9	1.35	

In New Orleans.

Size of Sewer	Pumping	Depth	Rate of Wages	Cost Per Cu. Yd.		Cost Per Lin. Ft.		
8 in.		7.5	$0.175	2.7 hr.	$0.40	1.1 hr.	$0.17	Uptown
8 in.		8.3	0.175	4.5 hr.	0.71	2.3 hr.	0.33	Downtown
10 in.		8.0	0.175	6.0 hr.	0.80	2.9 hr.	0.36	Downtown
10 in.		8.0	0.175	3.4 hr.	0.50	1.5 hr.	0.22	Uptown
10 in.		10.0	0.175	4.6 hr.	0.69	3.1 hr.	0.47	Downtown
12 in.		9.0	0.175	4.1 hr.	0.62	2.5 hr.	0.38	Downtown
12 in.		9.0	0.175	2.2 hr.	0.32	3.9 hr.	0.58	Uptown
15 in.		9.0	0.175	5.1 hr.	0.82	3.5 hr.	0.56	Downtown
18 in.		12.0	0.175	5.5 hr.	0.83	5.7 hr.	0.86	Downtown
18 in.		13.0	0.175	3.6 hr.	0.53	4.8 hr.	0.73	Uptown
22 in.		6.0	0.175	3.3 hr.	0.49	2.6 hr.	0.38	Downtown
22 in.		12.0		2.2 hr.	0.82	3.9 hr.	0.58	Uptown

Brick Sewer Masonry.

The Chicago hard sewer brick will average in size 8⅜ in. by 3¾ in by 2 7/16 in. An average of 6,000,000 brick laid in two and three ring sewers shows that 520 brick, as bought and counted in cars or wagons including breakage, are required per cubic yard of masonry. As it is customary to lay all bats of one-half brick or greater in the outer rings of the arch, the loss by breakage is trifling. As shipped from the brick yards sewer brick are uniformly of good quality. Any under burned or soft brick found in the kilns are broken up or sold for building brick.

The using of the bats as indicated is not detrimental to the quality of the work as the extrados is always thickly plastered with cement mortar, and all joints are thus well filled.

Utica natural cement is generally used in Chicago for mortar, for brick sewers. That this is satisfactory is shown on examinations of old work in which the erosion of the brick of the invert has proceeded faster than has that of the mortar. Portland cement makes a stiff mortar that does not work freely under the mason's trowel. Hence brick-work of sewers laid in Portland cement is apt to have a larger proportion of poorly made joints than if a natural cement had been used The remedy for this is to mix with the Portland cement a small quantity of Utica cement. The resulting mortar will be more *buttery* and easily worked.

Sewers generally, in the vicinity of Chicago, serve the double purpose of sanitary sewers and drainage of the soil also. Hence the requirement of being water tight does not obtain. This permits the customary practice of building the outer ring of the invert with the first six or eight courses of brick being laid tight together without mortar. The writer has built many sewers discharging into Lake Michigan or Calumet River, whose inverts have been from one to three feet below water level in sand trenches, in such locations that the use of well points would have been of no avail in the presence of so much water, and the use of water tight sheeting was not permissible with the prices obtainable for the work. By laying several courses without mortar and then following up with the haunches laid in rich mortar and also the inner course of brick likewise, sewers have been built in 10 or 15 in. of water, which, on subsequent examination and removal, have been found to be substantially true to form and strong. This practice is also useful for work in sandy, loamy, wet trenches where points cannot be used, but water has to be pumped from a sump in the trench. In Gary, Indiana, where such a sewer was built and then cut into for examination in several places, it was found that the brick lay with joints so tight as to prevent the entrance of a thin penknife blade. The sewer was clean, as the entering water carried no sand; the course grains of sand, or coarse sand and fine pebbles around the joints acted as filters. By the construction of such sewers the ground-water level at Gary, Hammond, Hegewisch, and other localities has been lowered from the natural ground surface by 6 to 8 ft., making possible the building of house cellars, in what had been swampy localities.

If a perfectly water-tight sewer with full joints is desired, the use of well points is imperative in wet, sandy soil. The points must be kept in service until the cement of the mortar has set hard, that is, for at least two or three hours. But points cannot be used in a sand carrying clay or loam, as this will choke the screens of the points.

BRICKWORK.

The organization of a brick-laying gang is as follows:

A foreman, whose duty it is to keep a steady supply of everything needed for the use of the masons, is placed on the berm of the trench. Each two bricklayers has a helper in the bottom. According to the depth of the trench there are one to three scaffold men for each tender and a brick tosser on the bank, and one mortar carrier. Two mortar makers will serve four masons. From two to six men are required to take down the arch centering of ribs and lagging, pass it ahead, and set it up again. It is uneconomical to work an odd number of masons, as the same number of auxiliaries can serve two masons as easily as one.

The average day's work of a mason working 8 hours was found to be 4,000 brick laid in place. The maximum number laid per day was an average of two days' work on a 2 ft. diameter two ring sewer in a moderately wet trench where an average of 7,583 brick were laid per man. The minimum happened to be on a larger and easier sewer to build where, however, other adverse circumstances cut the day's work to 2,700 brick. A safer average is 3,500 brick per man per day, at a cost of $28.20, or $8.05 per thousand for labor of the bricklaying gang.

Table 12, based on 4,000 brick per day, gives the out-put and rate of construction for various sizes of sewers which ought to be reasonably expected, as it is the rate maintained for four years' time

TABLE 12.

BRICKLAYING.

FORCE AND COST.

Dia. of sewer	2 ft. to 4 ft. Dia. 2 Rings.		4 ft. to 8 ft. Dia. 2 Rings.	
Bricklayers	4 @ $10.00	$40.00	6 men	$ 60.00
Tenders	2 @ 3.75	7.50	3 men	11.25
Scaffoldmen	2 @ 2.75	5.50	3 men	8.25
Brick tossers	2 @ 2.25	4.50	3 men	6.75
Brick wheelers	2 @ 2.00	4.00	4 men	8.00
Sand throwers	2 @ 2.25	4.50	3 men	6.75
Mortar mixers	2 @ 2.50	5.00	4 men	10.00
Mortar carriers	2 @ 2.25	4.50	4 men	9.00
Water boy	1 @ 1.50	1.50	1 man	1.50
Team	½ @ 6.00	3.00	1 team	6.00
Foreman	1 @ 5.77	5.77	1 man	5.77
Total	20½ men	$85.77	33	$133.27
Brick and cement teaming	4½ men at $6.00;	$27.00	7 men	42.00
Total	25 men =	$112.77	40 men =	$175.27
No. of men to 1 Bricklayer	6		6½	
Brick laid per men per day	4000		4000	
Brick laid per day—4 men	16000		6 men 24000	
Length of sewer per day's work and cost per foot.				
2 ft. 0 in. Dia.	139 ft.	$0.81	209 ft.	$0.83
2 ft. 6 in. Dia.	107 ft.	1.05	160 ft.	1.09
3 ft. 0 in. Dia.	102 ft.	1.10	153 ft.	1.15
3 ft. 6 in. Dia.	88 ft.	1.28	132 ft.	1.33
4 ft. 0 in. Dia.	75 ft.	1.50	112 ft.	1.55
4 ft. 6 in. Dia.	68 ft.	1.66	103 ft.	1.70
5 ft. 0 in. Dia.	55 ft.	2.08	83 ft.	2.10

Working an odd number of masons is as expensive an operation as one.

Tender, tossers, scaffoldmen, sand thrower, and mortar carrier can attend to two masons.

Brick laying per mason per day (Ave. of 28.177 ft. of work) 4009.

MANHOLES.

Brick manholes are usually built 3 ft. internal diameter of two bricks in thickness or 9 in. The inner ring is built with brick standing on end and bonded every fourth course with one course laid flat. The outer ring is built best of half bricks or bats laid flat.

The most economical way of building brick manholes is to use a light wooden *drum*, slightly conical in shape as a *form* against which to lay brick. The taper need not be over ½ in.

and is for the purpose of making it easy to raise the form as the brickwork requires. The height of the form or drum is usually 3 ft., so as not to make it too heavy for ease of handling. When iron steps are placed in the manhole, a slot can be cut into the drum an inch larger all around than the step for clearance.

In case steps are used they are best spaced approximately 16 in. apart; a width of 9 in. is sufficient. The best form of step is that used on telephone poles, in which the foot-hold or step is bent, or dropped an inch below the sides, so as to prevent a user's foot from slipping off sidewise. The ends should project through to the outside of the wall, and bend up an inch or two.

In building manholes or catch basins, two bricklayers should work together on account of requiring no more helpers than one mason. It is better to *raise* manholes when the bricklayers cannot work on the sewers, so as not to disorganize the main work of the masons; their work is to push construction of the sewer itself at top speed.

Manholes on pipe sewers are best built up to the center line of the sewer as soon as possible after the excavation is made, so that pipe laying may proceed without delay. In some cases it is possible to do this ahead of pipe laying, which is highly advantageous, and then complete the manhole, when the mason is not preparing another *bottom*.

The cost of such holes is shown in Table 13, in which is given actual costs for 178 manholes.

TABLE 13.

BRICK MANHOLE COSTS.

Size of Sewer	Height of Manhole	Labor Hours	Labor Cost	Brick	Cement Bbls.	Materials Cost	Total
4 ft. 6 in. brick	5.8	9.0	$ 5.32	713	1.4	$ 9.70	$15.02
3 ft. 6 in. brick	5.9	10.4	4.96	727	1.4	9.78	14.74
3 ft. 0 in. brick	5.3	11.1	4.95	626	1.3	9.81	13.76
2 ft. 0 in. brick	6.1	9.0	4.80	727	1.4	9.80	14.60
1 ft. 6 in. pipe	8.8	31.1	13.60	1262	2.6	13.50	26.80
1 ft. 3 in. pipe	8.4	31.0	13.75	1141	2.4	12.81	26.56
1 ft. 0 in. pipe	7.9	27.9	12.05	1100	2.2	12.10	24.15
Ave. brick	5.7	10.2	4.93	698	1.4	9.83	14.78
Ave. pipe	8.2	29.0	12.62	1168	2.4	12.80	25.42

Height of manholes for brick sewers is measured from extrados of arch; for pipe sewers it is the full height of the brick work.

The figures of Table 14 are summarized as follows:

TABLE 14.

BRICK MANHOLES.

Size	3 ft. diam. 7 ft. 11 in. high.	9 in. walls.
No. of brick each	1080	2.52 cu. yds.
No. of bbls. cement	2.3 bbls.	
Volume of masonry	0.3 cubic yard per lin. ft.	

	Each	Per Lin. Ft. of Height	Per Cu. Yd. of Masonry
Labor in hours	21.0 hrs.	2.65 hrs.	8.3 hrs.
Labor cost	$10.67	$1.36	$4.23

Ave. rate of wages $0.51, including masons, helpers, and team.

TABLE 15.

CONCRETE MANHOLE COSTS.

Concrete	Hand-mixed	Machine-mixed
Height	13 ft. 0 in.	11 ft. 3 in.
Inside diameter	3 ft. 6 in.	3 ft. 6 in.
Thickness of concrete	8 in.	8 in.
Concrete per lin. ft. of height	.37 cu. yd.	.37 cu. yd.
Number of manholes	28	10

COSTS PER MANHOLE.

	Hours	Cost	Hours	Cost
Haul of mixer			1.0	$0.45
Unloading sand and stone	2.2	$0.39	2.2	0.39
Unloading cement	0.9	0.18	0.9	0.18
Delivering to mixer	6.3	1.20	13.0	2.79
Mixing concrete	4.2	0.99	14.8	3.58
Wheeling concrete	5.2	1.20	11.7	1.95
Spreading and tamping	3.8	0.86	3.8	0.86
Runways			2.2	0.50
Forms	15.9	4.16	15.9	4.16
Total	38.5	8.98	65.5	14.86
Superintendence	1.5	.97	1.5	.97
Total	40.0	9.95	67.0	15.83
Cost per foot of height	3.1	0.77	6.0	1.40
Rate of wages per hour		0.25		0.234

COST PER CUBIC YARD OF CONCRETE.

	Hours	Cost	Hours	Cost
Haul of mixer			0.2.	0.10
Unloading sand and stone	0.5	0.09	0.5	0.09
Unloading cement	0.3	0.05	0.3	0.05
Delivering to mixer	2.9	0.63	2.9	0.63
Mixing concrete	2.1	0.52	2.6	0.61
Wheeling concrete	2.5	0.60	1.9	0.43
Spreading and tamping concrete	1.0	0.23	1.0	0.23
Runways			0.5	0.12
Forms	3.6	0.99	3.6	0.99
Total	12.9	3.11	13.5	3.25
Superintendence	.5	.26	.5	.26
Total	13.4	3.37	14.0	3.51

Brick catch basins are built in Chicago with a 2 in. plank bottom. The basins are 4 ft. internal diameter for 5 ft. 6 in. height and draw in to a diameter of 2 ft. in 20 in. of height. A 9 in. half trap is set with the bottom 3 ft. 6 in. above the planking. The brick work is 8 in. in thickness.

Catch basins are best built toward the close of piece of sewer work, as the soil is usually somewhat drained by the sewer, just built.

Steel Forms for Concrete Manholes.

Brick Catch Basins.

A small gang of diggers are organized so as to keep just ahead of the masons. Two men are put to digging each hole; no sheeting need be used, as the hole is open for so short a time as to render caving unlikely. The sides are sloped just enough to prevent slides. In case of wet ground, four to six well-points attached to a diaphragm pump will be needed.

As soon as bricklaying is begun, two men are put to digging for and laying the discharge pipes from the basins to the sewer.

The work so organized can be cheaply and quickly built.

Cost of basins and connections are given in Tables 16 and 17.

TABLE 16

CATCH BASIN COSTS.

Number on which costs are based, 212,—4 ft. diam. 8 ft high.
Soil, sand.

Labor cost, 345 hours			$13.22
Materials—1,100 brick	@ $ 6.00		6.60
60 B. M. lumber	@ 10.00		.72
2.2 bbls. cement	@ 0.636		1.40
1 9-in. half trap			1.45
1 cover			5.25
Superintendence			1.26
Total			$29.90

The planks for the bottom were cut out of old worn-out short sheeting which had done full service in the sewer construction and hence were charged to the catch basins at a low cost.

TABLE 17.

CATCH BASIN CONNECTIONS.

Labor		13.1 hrs.	$4.23
Materials	9 in. pipe	$5.50	5.76
	Cement	.18	
	Jute	.08	
Superintendence			0.50
	Cost per foot, $0.65½.		$10.49

TABLE 18.

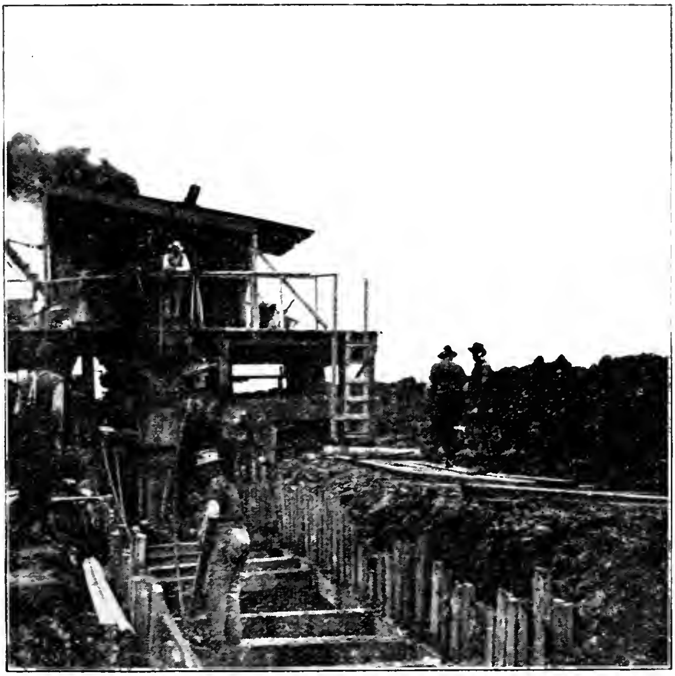
MANHOLES, CATCH BASINS AND CONNECTIONS.
Costs per foot of Main Sewer.

	Brick Sewers.	Pipe Sewers.
Manholes	$0.090	$0.19
Catch basins	0.253	0.253
Catch basin connections	0.089	0.089
Total	0.432	0.532

Concrete Sewer Masonry.

In the sewer work, Smith half yard concrete mixers were used. A source of considerable expense was found to be in the case of sewers running across country such as the sandy tracts of the Gary, Indiana, locality in making runways for the transportation of the machine along the sewer. At every shift of the machine, runways and elevated dumping platforms for charging the machine called for considerable work. In the new style of elevator charging boxes this expense is done away with. Two wheeled stone and sand barrows or buggies holding 4 cu. ft. each with ball-bearing wheels are better than any ordinary steel wheel barrow for economy of operation, repairs, and durability. The ordinary wheelbarrow holds but 2 cu. ft. and requires harder work at a slower speed, as much of the weight of the load is carried by the wheeler.

As the volume of concrete per lineal foot of sewer is comparatively small, the amount of work as indicated above amounts to so much per cubic yard that the economy of machine work over hand work is small—amounting to $0.24 per cu. yd. for labor, based on over 8,600 cu. yds. of work.



Arrangement of Movable Concrete Mixer for Sewer Work.

At Clearing, Illinois, on a job of 2,800 cu. yds. of concrete sewer, the invert was put in by machine and the arch was placed by hand, at costs of $1.70 and $2.40 per yard respectively; for machine and hand-work labor, the work was so arranged that the material track was but 20 ft. from the men, and the concrete was made right over the work.

In the case of the concrete manholes built, the hand-mixed concrete was made on a small mixing board close to the manhole, and the machine-mixed concrete was usually wheeled a considerable distance as the manholes were not complete until some days after concreting the sewer arch, and the machine had generally moved a considerably distance ahead. The costs for labor were: hand-mixing, $0.77, machine-mixing $1.40, per foot of height from manhole.

16.
1907-09

COST OF CONCRETE SEWERS PER LINEAL FOOT

DIA	LOCATION	LENGTH	DEPTH	EXCAVATION		SHEETING & BRACING		BACKFILLING		PUMPING		TOTAL TRENCHING		CONCRETE		SUPERIND'CE AND GEN'L. LABOR		TOTAL LABOR		MATERIALS.	TOTAL COST
		FT.	FT	HOURS	$	HRS	$	HRS	$	HRS.	$	HRS.	$	HRS.	$	HRS	$	HRS	$	$	$
48"	BL. FCES. IND. STEEL CO	894	0.0 TO 14.6	3	89	2	085	.6	.15	NONE		3.8	1125	32	.74	.7	.355	7.7	2 22		
57"	C.U.T. RY CLEARING ILL	2695	12.2	1.0	.37	1.0	.26	.5	.18	·	"	2 4	.81	39	1 00	.4	.15	6.7	1.97		
60"	OPEN HEARTH SEWER } INDIANA STEEL CO	415	16.7	12 0	2.79	2.9	60	1 9	46	2 3	51	19.6	4.36	5.3	1.23	3.4	1.43	28.0	7.02		
"	" " GARY IND	461.5	19.3	9 2	2 18	3 4	.77	1 8	.53	2.0	.41	16.4	3.89	5.7	1.22	2 0	.70	24 1	5 81		
63"	C.U.T. RY CLEARING ILL	2666	13.7.	1.3	.55	1.2	34	.5	19	2	.05	3.2	1.13	4 4	1.06	.2	.16	7.8	2.35	2.06	4.41
66"	" " "	1882	16.7	1 6	71	1 4	.38	.9	.26	NONE		3 9	1.35	5.7	1.39	.8	.27	10.4	3.01	2.19	5.20
72"	MILL SEWER } INDIANA STEEL COMPANY GARY IND.	576.5	12.8	4 8	1 53	2 1	52	.1	.03	.5	.13	7.5	2.21	5.3	1.15	1.3	.56	14.1	3 92		
"	BL. FCES.	275.5	15.2	7.9	2 14	2.8	80	.3	.17	1.4	.45	13.4	3.56	5.6	1.28	2.4	1 03	20.4	5.87		
"	MILL "	1910.	16.0	5.4	1.62	2.6	.79	.8	.24	.5	.12	9.3	2.77	5.3	1 36	.9	.50	16.5	4.63		
"	MERCHANT MILL	1213	19.7	10.8	3.04	4.7	76	1 0	.71	.7	.16	17.2	4.67	5.7	1 29	.9	.54	23 8	6.50		

1907-10.

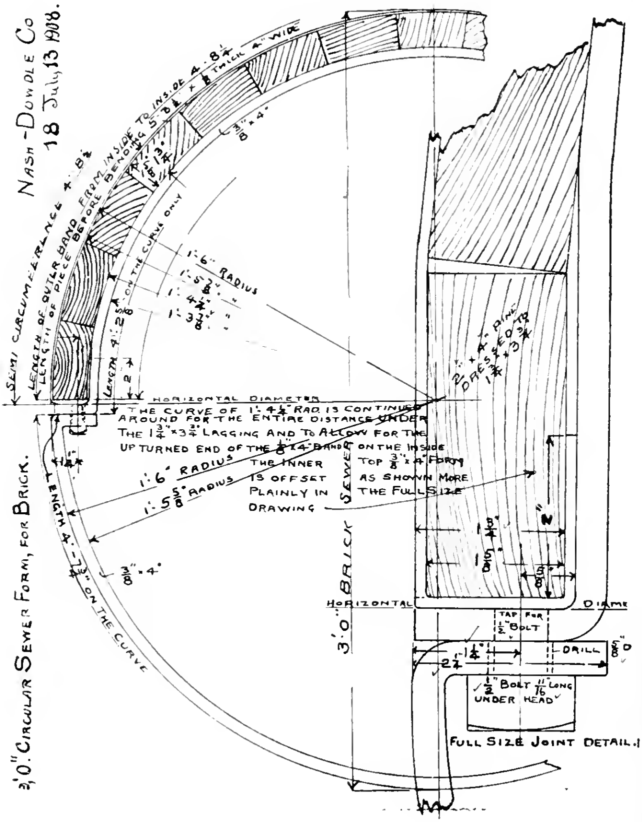
COST OF CONCRETE PER CUBIC YARD, LABOR ONLY

DIA OF SEWER	LOCATION	QUANTITY OF CONCRETE CU YDS	CEMENT SAND STONE TO MIXER		CEMENT SAND STONE TO MIXING BOARD		MACHINE MIXING		HAND MIXING		DELIVERY OF CONCRETE		TAMPING		PLASTERING		FORMS		RUNWAYS		TOTAL FOR MACHINE MIXING		TOTAL FOR HAND MIXING		RATE OF WAGES	THICKNESS OF WALL	CU YD PER LIN FOOT
			H'RS	$	HRS	$	H'RS	$	H'RS	$	H'RS	$	H'RS	$	HRS	$	H'RS	$	HRS	$	H'RS	$	HRS	$	$		CU YD.
48"	BL FCE SEWER IND STEEL CO	324	29	65			18	.43			1.5	34	8	17			12	.34	.5	11	8.7	2 04			.24	8"	.36
57"	CULV'RY CLEARING ILL	1300	29	58	28	60	9	25	23	59	15	.37	2	07			.6	.18			7.3	1 90	8.7	2 26	26	"	.48
60	OPEN HEARTH SEWER I STEEL CO	2[illegible]3.			37	70			22	46	18	33	10	25			15	.33	4	07			10.3	2 15	.21	10"	.57
60'	" " "	237.	35	73			18	42			8	18	8	18	12	.46	22	67			9.1	2.19			.24	"	"
63"	CULV'RT SEWER CLEARING ILL	1424	23	48	37	74	9	17	2.5	59	15	34	4	10	12	.43	8	.23			7.1	1.75	101	2.43	.26	9"	.53
66"	" "	1380.	2.1	.45	371	.73	8	11	25	.59	15	.34	4	10	10	39	.9	.23			65	1 68	10 0	2.38	.25	"	68
72"	MILL IND STEEL CO	1592.	23	57			10	30			10	25	7	19			6	.18	.4	08	6.0	1.56			26	12"	.82
"	" " "	461			18	33			15	33	25	53	INCLUDED				.9	.22					6.7	1.45	22	"	"
"	MERCHANT MILL SEWER	1438.	24	46			13	.32			2.5	.56					6	18			68	1.52			.22	"	"
"	BL FURNACE "	220			11	34			13	29	22	.52	.	. .	AVE OF 10		18	44					6.0	1 59	25	"	"
	TOTAL OR AVERAGE	8639.	2.5	54	29	58	12	28	20	48	14	.32	6	15	3	13	11	.29	.4	.09	75	1 80	8.7	2.04			
	MANHOLES GARY																				19.6	3.27	13.2	2.90		8"	
	" CLEARING																							2 19		"	
	GUTTER INLETS	20.																					12.6	3.95	32		
	OUTFALL ADDISON ST CHICAGO	184			17	.68			10	.35	17	.62	.2	.08			10	.35					5.7	2 83	.44		
	WATER TOWER FOUN'ON GARY }	635					.6	.23									1.2	47		}	94	3.29			.37		
			DRAYAGE		3.3 H'RS.	$	1.26		UNDIVIDED 4.0 H'RS $1.23																		
	HAMMER SHOP FOUN'DY KENSINGTON	326	UNDIVIDED		3.3 ..	$	1 35										1.7	.83					5.0	2 18	.43		
	GRANULATING PIT IROQUOIS IRON CO	340	"		7.3 "		1.26		UNLOADING MAT'L'S FROM CARS 1.7 H'R $0.29								20	.45					10.4	1 86	.18		

Arch.

In building a concrete sewer it is best to build the invert up to a height of 12 to 18 in., forming it by mold boards set every 20 ft. or so. When this is hard, the ribs and lagging for the rest of the sewer are set up, and concreting carried to completion.

The operations are timed so that concreting of the invert is done in the afternoon. Centers set up early in the morning is followed immediately by concreting the arch.


Nash-Dowdle Co
18 July 13 1908.
3'0" Circular Sewer Form, for Brick.
Semi circumference 4'-8¼"
Length of outer band from inside to ins. of 4'-8¼" thick 4" wide
Length of piece before bending 5'-8¼" × ⅜"
⅜" × 4"
1'-6" Radius
1'-5⅞"
1'-4½"
1'-3⅞"
Length 4'-2⅝" on the curve only
Length 2
Horizontal Diameter
The curve of 1'-4½" Rad. is continued around for the entire distance under the 1¾" × 3¾" lagging and to allow for the upturned end of the ⅜" × 4" band on the inside
1'-6" Radius
1'-5⅝" Radius
The inner is offset plainly in drawing
Top ⅜" × 4" form as shown more the full size
2" × 4" Pine dressed to 1¾" × 3¾"
1½"
Length 4'-2" on the curve
⅜" × 4"
3'0" Brick Sewer
1¾"
1⁵⁄₁₆"
⅝"
4"
Horizontal Diame
Tap for ½" bolt
1¼"
2¼"
Drill ⅝"
½" Bolt 11⁄16" long under head
Full Size Joint Detail.

Invert.

Form for 3-ft. Circular Brick Sewer.

Bricklaying for Buildings.

The hammer shop of the Chicago Drop Forge & Foundry Co. was built of 13 in. and 17 in. common brick walls some 30 ft. high from floor to roof, and required 100,000 brick in its construction. The actual bricklaying cost per 1,000 brick, 6.36

hours, was $4.29, while the collateral operations of unloading brick, mortar, making scaffold-work, etc., 7.24 hours, cost $2.88.

21.
1907-09.

PIPELAYING COSTS PER LINEAL FOOT

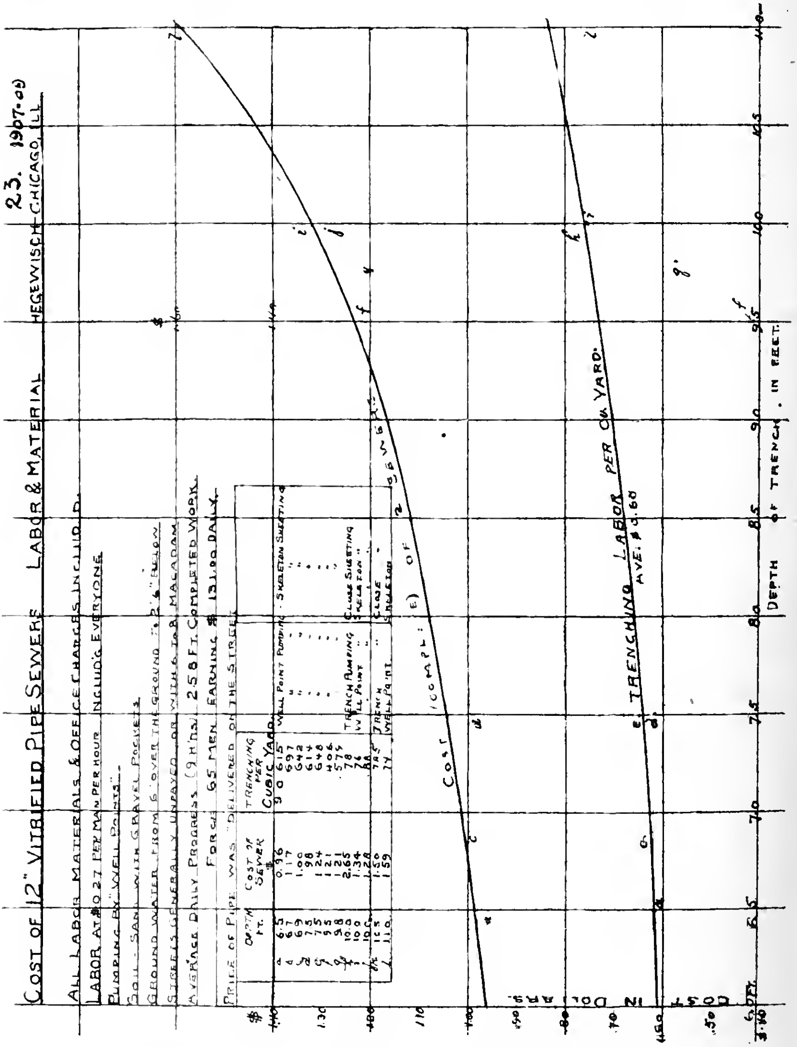
DIAM.	LENGTH	DEPTH	LABOR LAYING PIPE		PIPE	CEMENT		JUTE		OTHER SUPPLIES	TOTAL MAT'LS	TOTAL COST
			HOURS	COST		BBL.		LBS				
6"	277.0	10.0	.22	$0.064	$0.092	.012	$.008		$		$0.104	$.168
8	2974.	3.0 to 6.7	.08	.031	.14						.18	.211
10	176.	4.4 " 10.0	.33	.077	.225	.01	.007	.04	.002		.228	.305
12	13410.	6.5 " 11.0	.18	.06	.235	.017	.0114	.09	.0054		.25	.31
15	4002.	8.2 " 10.0	.18	.06	.333	.02	.013	.12	.0063		.353	.413
18	4843.	6.8 " 11.0	.33	.114	.50	.02	.013	.14	.007		.52	.634
20	1112.5	15.0	1.06	.22	.83			.36	.021	.009	1.22	1.54
24	510.	12.0	.70	.20	.98			.12	.007	.023	1.01	1.21

TOTAL 27,304.5 = 5.17 MILES

– COMPLETED SEWERS – TOTAL COST PER LIN FOOT ALL LABOR & MATERIALS

DIAM OF SEWER	6"		8"		10"		12"		15"		18"		20"		24"	
	HOURS	$	HOURS	$	HOURS	$				$			HOURS	$	HOURS	$
EXCAVATION		.007	.285	.075	.4	.11	1.07	.284	1.27	0.32	1.51	$ .42	6.5	1.30	1.8	.61
SHEETING & BRACING		.006	.015	.045	.17	.06	.28	.08	.28	.078	.46	.127	3.1	.744	.5	.20
BACKFILLING		.010	.150	.032	.13	.04	.33	.085	.30	.075	.31	.078	.7	.28	.2	.09
PUMPING		–	–	–	–	–	.50	.134	.68	.177	.56	.152	.6	.20	–	–
TOTAL TRENCHING		.023	.45	.152	.7	.21	2.18	.583	2.53	.65	2.84	.787	10.9	2.524	2.5	.90
PIPE LAYING		.065	.08	.033	.16	.044	.19	.063	.18	.06	.25	.092	.76	.22	.7	.20
GENERAL EXPENSE		.016	.08	.042	.08	.04	.16	.061	.15	.06	.17	.066	1.0	.40	.4	.19
TOTAL LABOR		.104	.61	.227	.44	.294	2.53	.607	2.86	.77	3.26	.945	12.66	3.144	3.6	1.29
MATERIALS & OFFICE		.104		.145		.244		.523		.70		.873		1.06		1.01
TOTAL COST PER FT.		$ .208	.61	$ .372		$ .538		$ 1.13		1.47		1.818		4.204		$ 2.30

A bricklayer's average 8-hour day's work was the laying of 1,257 brick. The cost of brick, mortar materials, coping, and lumber for scaffolding, was $8.90 per 1,000 brick, making a total cost of $16.07 per 1,000 brick. Had scaffolding and wooden horses, mortar boards, etc., been available from some other work, this cost would have been reduced $1.40 per 1,000 brick.



	DEPTH FT.	COST OF SEWER $	TRENCHING PER CUBIC YARD.		
a	6.5	0.96	$0 615	WELL POINT PUMPING	- SKELETON SHEETING
b	6 7	1 17	697	" "	"
c	6 9	1.00	642	" "	"
d	7 5	98	614	" "	"
e	7 5	1 24	648	" "	"
f	9 5	1 21	406	" "	"
g	9 8	1 21	.579	" "	"
h	10.0	2.65	78	TRENCH PUMPING	CLOSE SHEETING
i	10 0	1.34	76	WELL POINT "	SKELETON "
j	10 0	1.28	88	" "	" "
k	10 5	1.50	785	TRENCH "	CLOSE "
l	11 0	1 59	74	WELL POINT	SKELETON

An old wall 13 ft. high was taken down, and the brick were cleaned and piled at a cost of $0.56 per thousand.

A smooth red brick made at Hobart, Indiana, not quite as fine as the pressed red brick available in the Chicago market, makes a very presentable wall. On account of its finish, more care is required in laying than is the case with the Chicago common brick. In building a power house 220 ft. long and 30 ft. high of side walls, using a 13 in. wall with plain pilasters at the steel columns and corners, and three smaller buildings adjacent 370,000 brick were laid at the following costs for labor:

	Hours	Cost	Per 1,000 Brick Hours	Cost
Bricklayer foreman	337	$ 269.60	0.91	$0.72
Bricklayers	3,863	2,607.87	10.5	7.05
Helpers	4.285	749.85	11.6	2.02
Mortar mixers	717	154.15	1.94	0.40
Labor foreman	175	61.25	0.5	0.16
Labor (common)	2,078	363.65	5.68	0.97
Hoist operator	120	42.00	0.33	0.10
Carpenter foreman	85	42.50	0.03	0.11
Carpenters	324	113.40	0.90	0.30
Handy man	190	46.50	0.51	0.12
Timekeeper	185	55.50	0.50	0.15
Total	12,359	$4,506.27	33.4	$12.10

Teaming of scaffold, etc., to and from work and unloading of brick and sand from cars not included. Cost of washing walls inside and outside with acid is included. One half of the work was done with scaffolds hoisted by cables and winches as the rise of the brick work required. The rest of the scaffolding was the ordinary wooden staging.

Laying of Fire Brick.

In the building of a blast furnace plant 640,000 fire brick were used in the construction of gas flues from the hot blast stoves and boilers to the chimneys, and also for foundations of two blast furnaces. The flues were composed of 9 in. walls and arches and 4½ in. floors. As the flues were subsequently imbedded in massive concrete foundations, forms were built on the interior lines of the flues throughout. The fire brick laid in neat Portland cement grout were laid against the forms and then the concrete was built against the brick. The joints averaged 1/16 in. to ⅛ in. in thickness. Half of the cost of the forms was charged against the brickwork. Due to the presence of the forms, the masons laid brick much faster than if they had to build a wall by plumb and line, or against the concrete while working in the interior of the flues. The floors were paved with brick on edge laid on 2 in. of sand and grouted. The blast furnace foundations were in courses 3 ft. high and 9 ft. to 12 ft. thick.

The wages were for 8-hour days, masons $7.00, helpers $2.50, and foremen $3.75. Unloading brick from box cars and carefully piling same took 5 hrs. at $1.12½ per 1,000 brick.

The massive work was the handling of the exterior foundations of two blast furnaces. The form and dimensions of the work were such as to be exceedingly favorable to low costs

The brick were taken from cars on tracks immediately adjacent and parallel to the work. The mortar was 1 to 1 mixture of Portland cement and sand, and was mixed into a thin grout. This was poured over the brick from one quart dippers and the brick laid with joints varying from nothing to ⅛ in. in thickness. About 5% of the brick laid in the gas flues were laid as headers to project 4 in. into the concrete which was afterwards built up around it.

Including unloading brick, mortar men, tenders, carpenters or forms, and other laborers, there were ten men per bricklayer.

Table No. 19 gives the costs of fire-brick masonry:

TABLE 19.

Fire-Brick Masonry Labor.

	Brick Laid	Masons' Hours	Helpers' Hours	Brick Per Mason Per Day	Cost Per 1,000 Brick
Arches of flues	63,930	530	2,380	1,206	$14.45
9 in. walls of flues	232,395	490	4,450	4,110	6.48
Paving of flues	32,580	221	1,320	1,480	14.40
Total	328,905	1,241	8,150	2,652	8.73
Massive foundations	311,495	1,150	5,600	3,386	6.85
Total or average	640,400	2,391	13,750	2,720	7.81

TABLE 20.

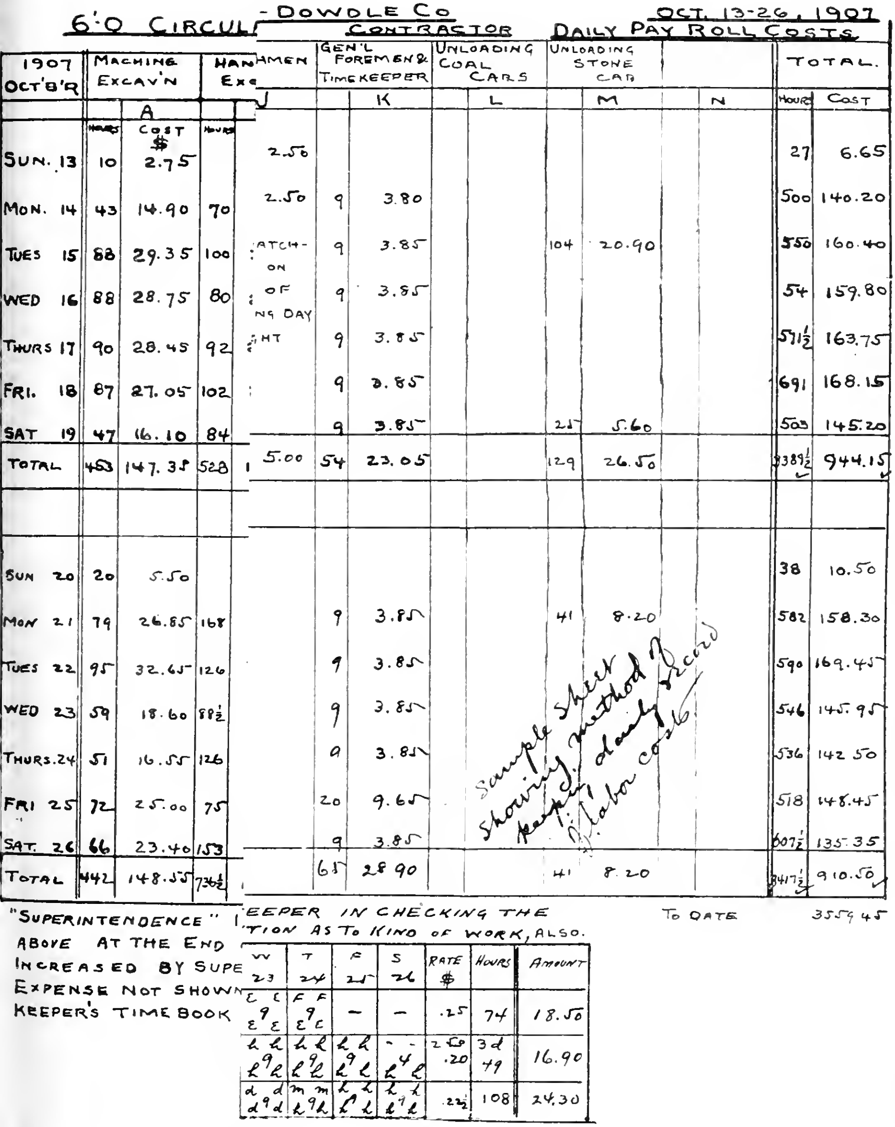
Fire-Brick Sizes.

Kind	Vol. of Brick Cu. In.	Brick Per Cu. Ft.	⅛-in. Joints Brick Per Cu. Ft.	Brick Laid
9 in. Straight $8\frac{7}{16}$x2½x$4\frac{1}{16}$	85.6	20.2	18.3	539,000
No. 1 Arch 8¾x4x$2\frac{1}{16}$ and 2½	79.7	21.7	19.7	60,000
No. 2 " 8¾x$4\frac{1}{16}$x1½ and 2⅛	64.3	26.9	24.2	3,000
No. 1 Key 8½x2½x2⅜ and 4	67.8	25.5	23.2	10,000
No. 2 " 8½x2½x3 and 3⅞	72.6	23.8	21.7	2,700
No. 3 " 8½x2½x2½ and 4	69.4	24.9	22.7	25,000
No. 4 " 8½x2½x2 and 4	63.8	27.1	24.5	1,700
Total				641,400

The average 9 in. straight fire-brick is 9x4½x2½ containing 101.25 cu. in., with *rubbed* joints; this will take 17 brick per cu. ft. of masonry.

Fire-brick masonry will take 700 lb. of plain ground clay per 1,000 brick. If laid with fire-brick dust, the clay may be reduced to 350 lb.

A few words in regard to the tables and diagrams, in addition to the foregoing, will make them understood.



1.

6'0 CIRCUL -DOWDLE CO CONTRACTOR

OCT. 13-26, 1907

DAILY PAY ROLL COSTS

1907 OCT'B'R	MACHINE EXCAV'N A Hours	MACHINE EXCAV'N A Cost $	HAND EXC Hours	...HMEN J	GEN'L FOREMEN & TIMEKEEPER K Hours	GEN'L FOREMEN & TIMEKEEPER K Cost	UNLOADING COAL CARS L Hours	UNLOADING COAL CARS L Cost	UNLOADING STONE CAR M Hours	UNLOADING STONE CAR M Cost	N Hours	N Cost	TOTAL Hours	TOTAL Cost
SUN. 13	10	2.75		2.50									27	6.65
MON. 14	43	14.90	70	2.50	9	3.80							500	140.20
TUES 15	88	29.35	100	ATCH- ON	9	3.85			104	20.90			550	160.40
WED 16	88	28.75	80	OF NG DAY	9	3.85							54	159.80
THURS 17	90	28.45	92	HT	9	3.85							571½	163.75
FRI. 18	87	27.05	102		9	3.85							691	168.15
SAT 19	47	16.10	84		9	3.85			25	5.60			503	145.20
TOTAL	453	147.35	528	5.00	54	23.05			129	26.50			3389½	944.15
SUN 20	20	5.50											38	10.50
MON 21	79	26.85	168		9	3.85			41	8.20			582	158.30
TUES 22	95	32.65	126		9	3.85							590	169.45
WED 23	59	18.60	88½		9	3.85							546	145.95
THURS. 24	51	16.55	126		9	3.85							536	142 50
FRI 25	72	25.00	75		20	9.65							518	148.45
SAT. 26	66	23.40	153		9	3.85							607½	135.35
TOTAL	442	148.55	736½		65	28 90			41	8.20			3417½	910.50

To Date 3559 45

Sample sheet showing method of keeping daily record of labor costs

"SUPERINTENDENCE" I
ABOVE AT THE END
INCREASED BY SUPE
EXPENSE NOT SHOWN
KEEPER'S TIME BOOK

EEPER IN CHECKING THE
TION AS TO KIND OF WORK, ALSO.

W 23	T 24	F 25	S 26	RATE $	HOURS	AMOUNT
E E 9 E E	F F 9 E E	—	—	.25	74	18.50
h h l 9 h	h h l 9 l	h h h 9 l	- - l 4 l	2 50 .20	3d 49	16.90
d d d 9 d	m m h 9 h	h h h h	h h h 9 h	.22½	108	24.30

WESTERN SOCIETY OF ENGINEERS
Vol. XVI. No. 9. Nov., 1911
Windett—Sewer Costs

1.

6'0 CIRCULAR CONCRETE "MILL" SEWER — INDIANA STEEL CO GARY IND. — NASH-DOWDLE CO CONTRACTOR — OCT. 13-26, 1907 DAILY PAY ROLL COSTS

1907 OCT'B'R	Machine Excav'n		Hand Excav'n.		Machine Backfill		Hand Backfill		Sheeting & Bracing Placing		Sheeting Pulling		Steam Pumping		Concrete Labor		Cement Dely.-Cars to Stores		Watchmen		Gen'l Foremen & Timekeeper		Unloading Coal Cars		Unloading Stone Car				Total.	
		A		B		C		D		E		F		G		H		I		J		K		L		M		N	Hours	Cost
	Hours	Cost $	Hours	Cost $		$		$		$																				
Sun 13	10	2.75													5	1.40			12	2.50									27	6.65
Mon 14	43	14.90	70	17.55					134	37.60	21	4.30	10	2.50	201	57.05			12	2.50	9	3.80							500	140.20
Tues 15	88	29.35	100	30.15					78	28.40			10	2.50	161	45.25			No watchman on acct of digging day & night		9	3.85			104	20.90			550	160.40
Wed 16	88	28.75	80	21.40					184	52.95			16	3.70	170	49.15					9	3.85							54	159.80
Thurs 17	90	28.45	92	25.55					63	21.05	36	9.15	10	2.50	271½	73.20					9	3.85							571½	163.75
Fri. 18	87	27.05	102	23.00			10	2.00	119	40.10	30	7.00	14	4.25	320	60.90					9	3.85							691	168.15
Sat 19	47	16.10	84	19.50					114	40.50			10	2.50	214	57.15					9	3.85			25	5.60			505	145.20
Total	453	147.35	528	137.15	No work this week		10	2.00	692	220.60	87	20.45	70	17.95	342½	344.10			24	5.00	54	23.05			129	26.50			3389½	944.15
Sun 20	20	5.50											18	5.00															38	10.50
Mon 21	79	26.85	168	43.90					66	23.15	9	2.00	10	2.50	200	47.85					9	3.85			41	8.20			582	158.30
Tues 22	95	32.65	126	33.20					78	26.45	27	5.50	10	2.50	245	65.30					9	3.85							590	169.45
Wed 23	59	18.60	88½	20.00					78	24.65	18½	3.70	10	2.50	283	72.65					9	3.85							546	145.95
Thurs 24	51	16.55	126	30.80					71	20.80	38	9.00	22	5.00	219	56.50					9	3.85							536	142.50
Fri 25	72	25.00	75	17.25			29	7.90	76	31.25	78	15.70	32	7.50	126	34.20					20	9.65							518	148.45
Sat 26	66	23.40	153	38.05			101½	22.00	55	17.00	25	5.00	22	5.00	176	21.05					9	3.85							507½	135.35
Total	442	148.55	736½	183.20			130½	29.90	424	143.30	195½	40.90	124	30.00	1259	297.55					65	28.90			41	8.20			3417½	910.50

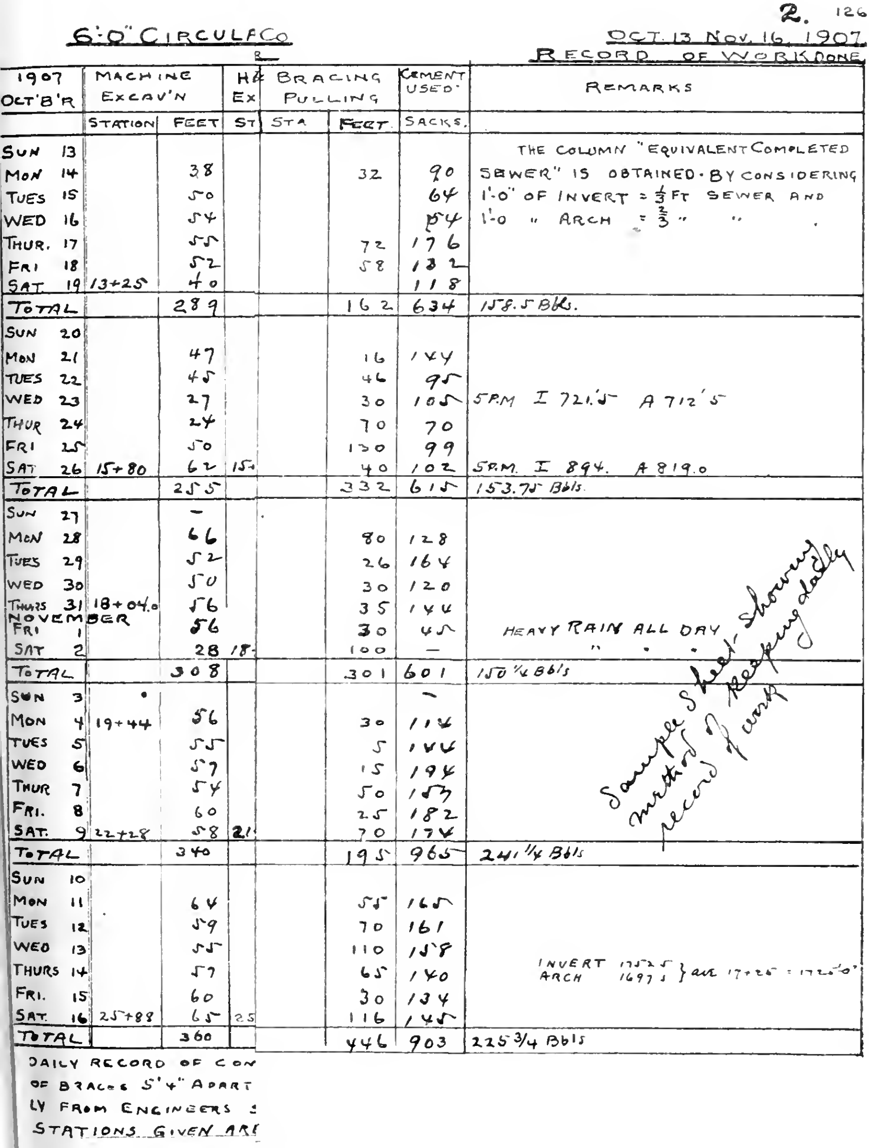
To date 3559.45

Sample sheet showing method of keeping daily record of labor costs

"SUPERINTENDENCE" ITEM "K" SHOWN ABOVE AT THE END OF THE JOB IS INCREASED BY SUPERINTENDENCE EXPENSE NOT SHOWN ON THE TIME KEEPER'S TIME BOOK

EXTRACT FROM TIMEBOOK — SHOWING HOW TIMEKEEPER IN CHECKING THE TIME OF THE MEN 4 TIMES A DAY MAKES THE DISTRIBUTION AS TO KIND OF WORK, ALSO.

Name 1907 Oct:	Sun 13	M. 14	T 15	W 16	T 17	F 18	S 19	Sun 20	M 21	T 22	W 23	T 24	F 25	S 26	Rate $	Hours	Amount
32 Hy Wilson	—	A B 9 C C	A B 9 B B	B B 9 B B	—	B B 4	B B 7 B -	—	E E 9 E E	E E 9 E E	E E 9 E E	F F 9 E C	—	—	.25	74	18.50
33 Jno Johnson	J 12 J	J 12 J	—	—	—	—	—	J 12 J	E E 9 E E	H L 9 L L	L L 9 L L	L L 9 L L	L L 9 L L	- - 4 L L	2.50 .20	3d 47	16.90
34 Wm White	—	d d 9 d d	d d 9 d d	F F 9 F F	F F 9 F F	F F 9 F F	F F 9 F F	—	L L 9 L d	d d 9 d d	d d 9 d d	m m 9 L L	L L 9 L L	L L 9 L L	.22½	108	24.30



2. 126

6:0" CIRCULFCo

OCT. 13 NOV. 16. 1907
RECORD OF WORK DONE

1907 OCT'B'R	MACHINE EXCAV'N		H& EX	BRACING PULLING		CEMENT USED	REMARKS
	STATION	FEET	ST	STA	FEET	SACKS.	
SUN 13							THE COLUMN "EQUIVALENT COMPLETED
MON 14		38			32	90	SEWER" IS OBTAINED BY CONSIDERING
TUES 15		50				64	1'-0" OF INVERT = 1/3 FT SEWER AND
WED 16		54				54	1'-0 " ARCH = 2/3 " "
THUR. 17		55			72	176	
FRI 18		52			58	132	
SAT 19	13+25	40				118	
TOTAL		289			162	634	158.5 Bbls.
SUN 20							
MON 21		47			16	144	
TUES 22		45			46	95	
WED 23		27			30	105	5 P.M I 721.5 A 712.5
THUR 24		24			70	70	
FRI 25		50			130	99	
SAT 26	15+80	62	15+		40	102	5 P.M. I 894. A 819.0
TOTAL		255			332	615	153.75 Bbls.
SUN 27		—					
MON 28		66			80	128	
TUES 29		52			26	164	
WED 30		50			30	120	
THURS 31	18+04.0	56			35	144	
NOVEMBER FRI 1		56			30	45	HEAVY RAIN ALL DAY
SAT 2		28	18+		100	—	" " "
TOTAL		308			301	601	150 1/4 Bbls
SUN 3						—	
MON 4	19+44	56			30	114	
TUES 5		55			5	144	
WED 6		57			15	194	
THUR 7		54			50	157	
FRI. 8		60			25	182	
SAT. 9	22+28	58	21		70	174	
TOTAL		340			195	965	241 1/4 Bbls
SUN 10							
MON 11		64			55	165	
TUES 12		59			70	161	
WED 13		55			110	158	
THURS 14		57			65	140	INVERT 1752.5 ARCH 1697.5 } ave 17+25 = 1725.0'
FRI. 15		60			30	134	
SAT. 16	25+88	65	25		116	145	
TOTAL		360			446	903	225 3/4 Bbls

Sample sheet showing method of keeping daily record of work

DAILY RECORD OF CON
OF BRACES 5'4" APART
LY FROM ENGINEERS :
STATIONS GIVEN ARE

732 b

2. 126

6'0" CIRCULAR CONCRETE "MILL" SEWER. INDIANA STEEL CO. GARY IND NASH-DOWDLE CO CONTRACTOR OCT. 13 NOV. 16. 1907. RECORD OF WORK DONE

1907 OCT'B'R	MACHINE EXCAV'N		HAND EXCAV'N		MACHINE BACKFILL		HAND BACKFILL		CONCRETE						SHEETING & BRACING				CEMENT USED	REMARKS
									INVERT		ARCH		EQUIV. COMP.	MAN-	PLACING		PULLING			
	STATION	FEET	STA	FT.	STA	FT	STA	FT.	STA.	FT.	STA.	FT	SEWER	HOLES	STA	FEET	STA	FEET	SACKS.	
SUN 13																				THE COLUMN "EQUIVALENT COMPLETED SEWER" IS OBTAINED BY CONSIDERING 1'-0" OF INVERT = ⅓ FT SEWER AND 1'-0 " ARCH = ⅔ " " .
MON 14		38		48								55				48		32	90	
TUES 15		50		48						48		24				48			64	
WED 16		54		48						55		— 0				48			54	
THUR 17		55		48						69		97.5		1		48		72	176	
FRI 18		52		50						55		69.0				48		58	132	
SAT 19	13+25	40		48						54		54.			12+95½	48			118	
TOTAL		289		295	NONE		NONE		11+57½	281	10+78½	299.5	293	1		288		162	634	158.5 Bbls.
SUN 20																				
MON 21		47		48						54		54				48		16	144	
TUES 22		45		48						54		42				48		46	95	
WED 23		27		48						—		73				48		30	105	5P.M I 721.5 A 712.5
THUR 24		24		48						75		—		1		48		70	70	
FRI 25		50		48						25		42				32		130	99	
SAT 26	15+80	62	15+70½	25					14+15.5	50	13+399	50			15+54.5	32		40	102	5P.M. I 894. A 819.0
TOTAL		255		265	NONE		NONE			258		261	260	1		256		332	615	153.75 Bbls.
SUN 27		—																		
MON 28		66		48						48		30.5				48		80	128	
TUES 29		52		48						54		84.		1		48		26	164	
WED 30		50		64						54		54.				64		30	120	
THURS 31	18+04.0	56		64					16+25.5	54	15+62.0	54			17+78.5	64		35	144	
NOVEMBER FRI 1		56		16						—	15+76.0	14		1		16		30	45	HEAVY RAIN ALL DAY
SAT 2		28	18+10½	—						—						—		100	—	" " "
TOTAL		308		240	NONE		NONE			210		236.5	228	2		240		301	601	150¼ Bbls
SUN 3																			—	
MON 4	19+44	56		48					16+82.0	54	16+17.5	36			18+84	89½		30	114	
TUES 5		55		64						80		48				64		5	144	
WED 6		57		64						80		80				64		15	194	
THUR 7		54		64						54		56				64		50	157	
FRI. 8		60		64						54		54				64		25	182	
SAT 9	22+84	58	21+61	46½					20+05.5	54	19+20	68			21+24	64		70	174	
TOTAL		340		350½	NONE		NONE			380		344	256	2		349½		195	965	241¼ Bbls
SUN 10																				
MON 11		64		64																
TUES 12		59		64						54		70				48		55	165	
WED 13		55		64						54		66				64		70	161	
THURS 14		57		64						54		56				64		110	158	
FRI 15		60		48						54		56				64		65	140	INVERT 1752.5 ARCH 1697.1 } AVE 17+25 = 1725'0"
SAT 16	25+88	65	25+09	32						57.5		50		1		64		30	134	
									23+27	54	22+74	56			24+86	48		116	145	
TOTAL		360		348	NONE		NONE			321.5		354	332	1		352		446	903	225¾ Bbls

DAILY RECORD OF CONCRETE MADE FROM COUNTING SPACES OF BRACES 5'4" APART BUT ACCURATELY CHECKED WEEKLY FROM ENGINEERS STATIONS

STATIONS GIVEN ARE AT THE CLOSE OF THE DAY'S WORK

SHEETING & BRACING DAILY RECORD WAS USUALLY COUNTED BY THE NUMBER OF LENGTHS OF 16'-0" LONG STRINGERS PLACED BUT WEEKLY THE ENGINEERS STATION MEASUREMENTS WERE TAKEN

Sample Sheet showing method of keeping daily record of work

SHEETING & BRA

4.
1907-10.

KIND OF PUMPING	SOIL	DIAM OF SEWER	COST	TOTAL COST			WAGES PER HOUR
			M'B.M.	CU YD.	LIN. FT.	M'B M	
		INCHES	$	$	$	$	$
WELL POINTS	SAND	12"	1.50	.095	.088	5.33	0.284
"	"	15	1.52	.096	.108	6.13	.281
"	"	18	1.70	124	.142	8.81	.295
"	"	24	2.40	.320	.381	9.65	.286
"	"	36	.54	.14	.38	5.67	.35
AVERAGE			1.53	16	.22	7.10	.30
TRENCH	SAND	8"					
PUMPING	"	10"					
"	"	12"	11.89	.165	354	15.87	.28
"	"	18	6.50	.614	.91	16.23	.32
"	"	20	1.50	.84	.80	10.67	.238
"	"	24	6.50	47	1.30	14.36	.284
"	"	30	6.69	.32	1.29	15.05	.294
"	"	36	4.30	.40	2.26	14.50	.285
"	"	42	5.85	.28	1.03	13.22	.296
"	"	48	6.83	29	1.47	16.13	.310
"	"	54	19.76	.44	1.66	19.75	.294
"	CLAY	57	7.62	.16	.58	11.41	.268
"	SAND	60	8.90	54	1.85	20.20	.217
"	CLAY	63	14.50	.16	.75	21.38	.287
"	"	66	11.25	.17	.95	18.90	.279
"	SAND	72					.272
AVERAGE			8.62	.38	1.19	16.00	.28

AS A GENERAL THING
2" "DUNN" BRACE SCREWS
WERE USED
SHEETING 2"×8"-12' TO 14'0"
STRINGERS { 4"×12" 16'0
6 ×8 "
BRACES 6"×6" SPACED
5'-4" C. TO C
DISTANCE APART OF
STRINGERS ABT 4'-6"
TO 5'-6" (VERTICAL)
IN SAND TRENCHES - USING
A CAP ON THE SHEETING IN
DRIVING A QUANTITY OF
SHEETING WOULD LAST
8 TO 12 DRIVINGS.

SHEETING & BRACING OF TRENCHES.

4.
1907-10.

KIND OF PUMPING	SOIL	DIAM. OF SEWER	DEPTH OF TRENCH	LUMBER PER FOOT OF TRENCH	KIND OF SHEETING	LABOR PER CUBIC YARD OF TRENCH		LABOR PER LINEAL FOOT OF TRENCH		LABOR PER 1000 FT. BM. OF LUMBER		MATERIALS COST PER			TOTAL COST			WAGES PER HOUR	
												CU. YD.	LIN. FT.	M' B.M.	CU. YD.	LIN. FT.	M' B.M.		
		INCHES	FT.	FT. B.M.		HOURS	$	HOURS	$	HOURS	$	$	$	$	$	$	$	$	AS A GENERAL THING
WELL POINTS	SAND	12"	8.7 FT.	16.7	SKELETON SHEETING	.24	.064	.22	.06	13.2	3.82	.031	.028	1.50	.095	.088	5.33	0.284	2" "DUNN" BRACE SCREWS
"	"	15	9.0	17.2	"	.24	.068	.28	.08	16.2	4.61	.028	.028	1.52	.096	.108	6.13	.281	WERE USED
"	"	18	10.4	15.7	"	31	.095	.39	.11	22.5	7.11	.029	.032	1.70	124	.142	8.81	.295	SHEETING 2"x8"-12' TO 14'0"
"	"	24	10.5	58.4	PART SKELETON	.85	.245	.85	.25	18.2	7.15	.075	.131	2.40	.320	.381	9.65	.286	STRINGERS {4"x12" 16'0
"	"	36	10.0	44.2	" "	.46	.13	.90	.27	19.2	5.72	.07	.19	.54	.14	.38	5.67	.35	6"x8 "
AVERAGE			9.4			.42	.12	.52	.16	18.0	5.68	.05	.082	1.53	.16	.22	7.10	.30	BRACES 6"x6" SPACED
																			5'-4" C. TO C
TRENCH PUMPING	SAND	8"	5.7		SKELETON SHEETING	.4	.11	.25	.05										DISTANCE APART OF
"	"	10"	4.4		"	.4	.12	.14	.05										STRINGERS ABT 4'6"
"	"	12"	9.3	50.0	"	.4	.13	.8	.18	14.0	3.98	.035	.174	11.89	.165	354	15.87	.28	TO 5'-6" (VERTICAL)
"	"	18	10.3	51.1	"	1.3	.43	1.5	.47	29.9	9.73	.184	.44	6.50	.614	.91	16.23	.32	IN SAND TRENCHES-USING
"	"	20	15.0	81.0	CLOSE DRIVEN	1.0	.24	3.1	.75	38.2	9.17	.56	.05	1.50	.84	.80	10.67	.238	A CAP ON THE SHEETING IN
"	"	24	10.8	67.0	SKELETON	1.0	.26	1.7	.71	28.0	7.86	.18	.59	6.50	.47	1.30	14.36	.284	DRIVING A QUANTITY OF
"	"	30	12.0	61.7	"	.9	.29	2.5	.72	33.1	10.05	.13	.61	6.69	.32	1.29	15.05	.294	SHEETING WOULD LAST
"	"	36	7.9	65.5	"	1.1	.33	2.1	.60	27.2	7.89	.11	1.40	4.30	.40	2.26	14.50	.285	8 TO 12 DRIVINGS.
"	"	42	14.6	81.4	"	.6	.17	2.3	.66	29.2	8.53	.11	.87	5.85	.28	1.03	13.22	.296	
"	"	48	14.3	76.0	"	.8	.17	3.4	.85	37.1	9.30	.12	.62	6.83	29	1.47	16.13	.310	
"	"	54	15.5	76.2	"	.8	.22	3.6	1.03	425	12.15	.34	1.66	19.76	.44	1.66	19.75	.294	
"	CLAY	57	12.2	50.0	SKELETON	.3	.07	1.0	.26	18.6	5.15	.12	63	7.62	.16	.58	11.41	.268	
"	SAND	60	18.0	67.8	CLOSE DRIVEN	.4	.43	3.2	.68	53.0	11.30	.14	1.17	8.90	.54	1.85	20.20	.217	
"	CLAY	63	15.4	50.0	SKELETON	.3	.73	1.2	.34	23.3	6.68	.09	.41	14.50	.16	.75	21.38	.287	
"	"	66	16.7	50.0	"	.3	.07	1.4	.38	27.2	7.70	.10	.59	11.25	.17	.95	18.90	.279	
"	SAND	72	14.9	62.0	CLOSE DRIVEN	.4	.10	3.1	.72	41.3	11.53							.272	
AVERAGE			12.3			.7	.24	2.0	.53	31.6	8.64	.17	.67	8.62	.38	1.19	16.00	.28	

5.

Cost of F

Aug-Nov. 1909.

Location	Size of Sewer	Leng F	Per Lin. Foot Labor Cost	Per Lin. Foot Labor & Mat'ls	Cost per Hour of Pump'g	Cost per Point
Erie Ave.	18"	61				
Ontario "	"	6				
Carondelet "	"	4				
Houston "	"	4				
Total or Average		21	.246	.34	1.71	.44
Erie Ave.	15"	6				
Superior "	"	6				
Carondelet "	"	6				
Ontario "	"	6				
Houston "	"	6				
Buffalo "	"	6				
Total or Average		40	.18	.25	1.81	
Erie S. Ave.	12"	8				
Buffalo "	12"	11				
Superior "	"	12				
Ontario "	"	11				
Houston "	"	3				
Superior "	"	6				
Ontario "	"	6				
Houston "	"	13				
Carondelet "	"	13				
Erie "	"	13				
Buffalo "	"	6				
Total or Average		100	.17	.26		
	Brick				15	
Howard Ave.	3'0"	9	.22	.35		
136th St.	2'0"	5				
Commercial Ave	"	13				
Total or Average "		19	.28	.39		

Pipe Sewers	161	.18	.263
Brick "	28	.26	.38
Total or Average	19	.199	.28

In each lin. 6 ft. of trench were 4 points
in 19038 ft. of sewer were
19038 × $\frac{4}{6}$ = 12700 points.

The cost per point was

1.09 hrs.	$0.298	Labor.
	0.129	Mat'l.
	0.427	Total.

Per Cu. Yd. of Excav'n.

	.8	Point
0.58 hr.	$0.166	Labor
	0.069	Mat'ls.
	0.235	Total

Per Lin. Ft. of Trench

0.72 hr.	$0.200	Labor
	0.086	Mat'ls.
	0.286	Total.

In each 6.0 lin ft o
equal to 2/3 of a
the "points" used
3'-0" hose conne
connecting to
the best wor
from mains hal
words for 300'-0
would have been

arger than 2½" or 3" while better on account of
cross sectional areas permitting better flow
inordinately heavy to shift or move along the
as well as expensive due to the many valves
tees etc. The first cost & operating costs
excessive.

5.

AUG-NOV. 1909.

COST OF PUMPING BY WELL POINTS

HEGEWISCH - CHICAGO ILL.

NASH-DOWDLE CO.
CONTRACTOR

LOCATION	SIZE OF SEWER	LENGTH FT.	DEPTH FT.	NO. OF POINTS USED.	HOURS OF PUMP'G	LABOR HOURS	LABOR COST	MATERIALS	TOTAL COST	VOLUME OF EXCAVATION CU. YDS.	COST PER CU. YARD LABOR HOURS	COST PER CU. YARD LABOR COST	COST PER CU. YARD LABOR & MAT'LS	COST PER LIN. FOOT LABOR HOURS	COST PER LIN. FOOT LABOR COST	COST PER LIN. FOOT LABOR & MAT'LS	COST PER HOUR OF PUMP'G	COST PER POINT
ERIE AVE.	18"	661	11.0	440	120	446	$119.75	$ 51.70	$171.45	810								
ONTARIO "	"	664	10.6	442	96	607	155.75	51.70	207.45	800								
CARONDELET "	"	423	10.2	275	120	467	141.00	36.85	177.85	765								
HOUSTON "	"	420	8.2	425	72	357	93.30	46.50	139.80	444								
TOTAL OR AVERAGE		2168	10.2	1502	408	1877	509.80	186.76	696.55	2819	.7	.18	.25	.86	.246	.34	1.71	.44
ERIE AVE.	15"	669	10.0	445	96	372	92.65	46.95	139.60	770								
SUPERIOR "	"	660	9.5	440	72	486	122.20	46.35	168.85	745								
CARONDELET "	"	672	9.2	447	84	320	96.80	58.85	155.65	939								
ONTARIO "	"	664	9.0	442	96	437	112.45	46.30	158.75	664								
HOUSTON "	"	669	8.3	445	84	403	106.33	54.95	161.28	615								
BUFFALO "	"	668	8.2	440	120	678	178.55	46.75	225.30	910								
TOTAL OR AVERAGE		4002	9.0	2695	552	2696	708.98	300.15	1009.43	4643	.6	.15	.22	.67	.18	.25	1.81	
ERIE S. AVE	12"	831	10.5	554	108	639	169.10	63.65	232.75	1080								
BUFFALO " SOUTH OF 134TH ST.	12"	1163	10.2	775	156	1000	261.00	64.45	325.45	1310								
SUPERIOR "	"	1298	9.8	865	192	765	216.00	76.57	292.57	1400								
ONTARIO "	"	1173	9.5	782	156	817	219.95	95.95	315.90	1325								
HOUSTON "	"	370	9.2	303	48	305	81.30	59.25	140.55	390								
SUPERIOR "	"	670	9.0	446	72	593	153.80	72.05	225.85	1060								
ONTARIO " NORTH OF 134TH ST.	"	668	8.0	444	72	405	119.50	43.75	163.25	370								
HOUSTON "	"	1337	7.5	890	120	463	120.70	78.10	198.80	1050								
CARONDELET "	"	1332	6.7	885	108	572	155.09	101.80	256.89	1200								
ERIE "	"	1340	6.6	894	96	567	143.00	97.50	240.50	1000								
BUFFALO "	"	668	6.5	444	48	330	78.35	66.55	145.90	490								
TOTAL OR AVERAGE		10019	8.3	7322	1176	6456	1717.79	819.62	2538.41	10675	.6	.16	.23	.6	.17	.26		
	BRICK SEWERS.																	
HOWARD AVE	3'0"	932	11.0	650	280	716	204.15	118.60	332.75	2514	.3	.05	.13	.8	.22	.35		
136TH ST	2'0"	581	10.0	354	144	613	170.95	66.10	677.05	1075								
COMMERCIAL AVE	"	1336	9.7	890	264	1397	370.10	146.50	516.60	2160								
TOTAL OR AVERAGE	"	1917	9.9	1244	408	2010	$541.05	$ 212.60	$753.65	3235	.6	.17	.25	1.0	.28	.39		

SUMMARY.

PIPE SEWERS	16189.	8.65	11563	2136	11029	2936.57	1306.52	4244.39	18137	0.61	.17	0.236	0.64	.18	.263
BRICK "	2849.	10.3	1894	638	2726	745.20	331.20	1086.40	4647.	.48	.16	0.235	.95	.26	.38
TOTAL OR AVERAGE	19038.	9.0	13457	2774	13755	$3781.77	$ 1637.72	$5330.79	22784	0.6	.165	.236	.68	.199	.28

IN EACH LIN. 6 FT. OF TRENCH WERE 4 POINTS IN 19038 FT. OF SEWER WERE 19038 × 4/6 = 12700 POINTS.

THE COST PER POINT WAS

1.09 HRS.	$0.298	LABOR.
	0.129	MAT'L.
	0.427	TOTAL

PER CU. YD. OF EXCAV'N.

	.8	POINT
0.58 HR.	$0.166	LABOR
	0.069	MAT'LS.
	0.235	TOTAL

PER LIN. FT. OF TRENCH

0.72 HR.	$0.200	LABOR
	0.086	MAT'LS.
	0.286	TOTAL.

IN EACH 6 LIN FT OF TRENCH ARE 4 WELL POINTS — 2 ON EACH SIDE OF THE TRENCH. EQUAL TO 2/3 OF A POINT PER LIN FT. OF TRENCH.

THE "POINTS" USED WERE 1¼" DIAM - 30" OF PERFORATED, SCREENED INLET, 13'0" LONG OVER ALL 3'-0" HOSE CONNECTIONS TO 2" MAINS ON EA. SIDE OF TRENCH. CONNECTING TO 6" x 7½" x 6" DUPLEX STEAM PISTON PUMP BY 4" SUCTION HOSE.

THE BEST WORKING CONDITION WAS TO HAVE THE SUCTION OF THE PUMP DRAW FROM MAINS HALF OF WHICH WERE AHEAD OF THE PUMP & HALF BEHIND. IN OTHER WORDS FOR 300'-0" OF TRENCH, 180 POINTS, 4" SUCTION TO PUMP OF THIS SIZE PUMPING WOULD HAVE BEEN BETTER & QUICKER DONE HAD 3" MAINS BEEN USED INSTEAD OF 2" MAINS.

MAINS LARGER THAN 2½" OR 3" WHILE BETTER ON ACCOUNT OF RELATIVE CROSS SECTIONAL AREAS PERMITTING BETTER FLOW WOULD BE INORDINATELY HEAVY TO SHIFT OR MOVE ALONG THE TRENCH AS WELL AS EXPENSIVE DUE TO THE MANY VALVES FLANGES TEES ETC. THE FIRST COST & OPERATING COSTS WOULD BE EXCESSIVE.

COM 7. 1907-09

DIA.	LOC	PING COST	BACK-FILLING HOURS	BACK-FILLING COST	TOTAL LABOR HOURS	TOTAL LABOR COST	MAT'LS COST	TOTAL MAT'LS & LABOR
	BOX	.07			6.2	1.22	.52	1.74
			.1	.022	.65	.147		
6"	ALL				.34	.08		
8"	L.S.		.19	.04	.51	.112		
"	C.L.				.2	.082		
"					2.0	.56		
10			.15	.03	.85	.20		
"			.22	.04	.8	.21		
12	"	.01	1	.04	1.5	.32		
"	ALL			.44		1.08		
"	"			.053		.43		
"	"		.2	.065	1.5	.45		
"	BU	.12	.2	.034	1.2	.304	.143	.447
"	CARO	.117	.29	.073	1.93	.54	.108	.648
"	ERI	.107	.3	.073	1.4	.376	.102	.478
"	HOU	.09	.19	.065	1.5	.447	.08	.527
"	ONT	.18	.3	.08	1.9	.53	.10	.63
"	SUF	.23	.1	.025	1.9	.502	.154	.656
"		.166	.3	.065	2.1	.551	.084	.635
"	HOU	VATION	.2	.042	4.4	.902	.125	1.027
"	ONT	.188	.4	.089	2.4	.646	.112	.758
"	HOU	.18	.25	? .060	2.19	.648	.135	879
"	BUF	.223	.4	.074	3.1	.772	.082	.854
"	ER	.20	.6	.14	3.2	.76	.11	.87
15	BUI	.27	.4	.09	3.1	.77	.11	.88
"	ON	.17	.85	.14	2.9	.695	.11	.805
"	HO	.157	.22	.07	1.73	.517	.122	639
"	CA	.145	.25	.075	2.29	.64	.11	.75
"	SUF	.184	.2	.043	2.7	.635	.11	.745
"	ER	.138	.15	.033	2.45	.64	.112	.752
18	HOU	.144	.23	.073	2.28	.69	.13	.82
"		.04	.08	.08	2.52	.778	.273	1.051
"	CAR	.03	.02	.07	6.1	1.83	.09	1.92
"		.333	.02	.077	3.25	1.05	.13	1.18
"	ON	.233	.7	.167	3.8	.976	123	1.099
"	ER	.181	.25	.053	2.707	.735	.124	.859
"	C.L.	.02	.1	.035	1.5	.37		
"		.03	.1	.04	2.4	1.01	.10	1.11
20"	ALL	.22	.7	.28	10.9	2.546	.13	2.676
	AV							

COMPLETE COST OF TRENCHING PER LINEAL FOOT OF SEWER

7. 1907-09

Dia.	Location	Length	Soil	Pumping	Depth	Hand Digging		Scraper Digging		Machine Digging		Sheeting & Bracing		Pumping		Back-Filling		Total Labor		Mat'ls	Total Mat'ls & Labor
						Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Cost	
	Box Flume Gary	733	Sand	T.P.	8.0	5.3	$ .97					.7	.18	.2	.07			6.2	1.22	.52	1.74
	" Hegewisch	2248	Clay Sand	"	2.5	.55	.125									.1	.022	.65	.147		
6"	Alley 8,9,10. Gary	800	Sand	None	5.0													.34	.08		
8"	L.S.&M.S.Ry. Pine Ind.	1878	"	"	"	.32	.072									.19	.04	.51	.112		
"	C.L.S.&E.Ry. Kirk Yard	858	"		5.7													.2	.082		
"	" "	33	"		20	2.0	.56											2.0	.56		
10	" "	767	"		4.4	.56	.125					.14	.045			.15	.03	.85	.20		
"	" "	96	"		4.5	.5	.11	.1	.06							.22	.04	.8	.21		
12	" "	1200	"		7.5	.7	.16	.1	.061			.5	.13	.1	.01	1	.04	1.5	.32		
"	Alley 8 Gary	400	"		8.0	1.64	.37					1.0	.27				.44		1.08		
"	" 9 "	425	"	None	9.4	.7	.15		.16			.234	.065				.063		.43		
"	" 10 "	425	"	"	11.4	.5	.108	.52	.20			.3	.08			.2	.065	1.5	.45		
"	Buffalo Av. Hegewisch	668	"	Points	6.5	.5	.15							.5	.12	.2	.034	1.2	.304	.143	.447
"	Carondelet " "	1332	"	"	6.7	1.11	.32					.1	.03	.43	.117	.29	.073	1.93	.54	.108	.648
"	Erie " "	1340	"	"	6.9	.5	.143					.2	.053	.4	.107	.3	.073	1.4	.376	.102	.478
"	Houston " "	1337	"	"	7.5	.8	.243					.17	.05	.34	.09	.19	.065	1.5	.447	.08	.527
"	Ontario " "	668	"	"	7.5	.8	.20					.2	.07	.6	.18	.3	.08	1.9	.53	.10	.63
"	Superior " "	670	"	"	9.5	.8	.212					.1	.035	.9	.23	.1	.025	1.9	.502	.154	.656
"	" " "	1298	"	"	9.8	.94	.242					.26	.078	.6	.166	.3	.065	2.1	.551	.084	.635
"	Houston " "	100	"	T.P.	10.0	2.4	.53					1.8	.32	In Excavation		.2	.042	4.4	.902	.125	1.027
"	Ontario " "	1173	"	Points	"	1.1	.30					.2	.069	.7	.188	.4	.089	2.4	.646	.112	.758
"	Houston " "	370	"	"	"	1.1	.373					.2	.071	.82	.18	.25	$ .060	2.19	.648	.195	879
"	Buffalo " "	1163	"	"	10.5	1.4	.352					.4	.123	.9	.223	.4	.074	3.1	.772	.082	.854
"	Erie " "	831	"	"	11.0	1.5	.35					.3	.07	.8	.20	.6	.14	3.2	.76	.11	.87
15	Buffalo " "	668	"	"	8.2	1.3	.30					.4	.11	1.0	.27	.4	.09	3.1	.77	.11	.88
"	Ontario " "	664	"	"	9.0	1.25	.332					.16	.053	.64	.17	.85	.14	2.9	.695	.11	.805
"	Houston " "	669	"	"	8.3	.6	.20					.31	.09	.6	.157	.22	.07	1.73	.517	.122	.639
"	Carondelet " "	672	"	"	9.2	1.26	.325		.01			.3	.085	.48	.145	.25	.075	2.29	.64	.11	.75
"	Superior " "	660	"	"	9.5	1.5	.33					.3	.068	.7	.184	.2	.043	2.7	.635	.11	.745
"	Erie " "	669	"	"	10.0	1.5	.407					.21	.062	.59	.138	.15	.033	2.45	.64	.112	.752
18	Houston " "	661	"	"	9.5	1.22	.37					.33	.103	.5	.144	.23	.073	2.28	.69	.13	.82
"	" " "	116	"	T.P.	10.0	.92	.211					1.5	.447	.02	.04	.08	.08	2.52	.778	.273	1.051
"	Carondelet " "	247	"	"	10.5	3.64	.946	.4	.164			1.95	.62	.013	.03	.02	.07	6.1	1.83	.09	1.92
"	" " "	423	"	Points	"	.87	.28	.43	.17			.61	.19	1.10	.333	.02	.077	3.25	1.05	.13	1.18
"	Ontario " "	664	"	"	"	1.9	.493					.3	.082	.9	.233	.7	.167	3.8	.976	123	1.099
"	Erie " "	661	"	"	11.0	1.4	.399					.34	.102	.717	.181	.25	.053	2.707	.735	.124	.859
"	C.L.S.&E.Ry Kirk Yard	825	"	T.P.	6.8	1.0	.24					.35	.075	.05	.02	.1	.035	1.5	.37		
"	" Pine	1422	"	"		1.2	.42		.19			1.0	.33	.1	.03	.1	.04	2.4	1.01	.10	1.11
20"	Alley 8 Gary	1126.5	"	"	15.0	6.0	1.09	.5	.212			3.1	.744	.6	.22	.7	.28	10.9	2.546	.13	2.676
	Average or Total	30958.5																			

Co͟rER. 8. 1907-09.

Lo		G	BACK-FILLING		TOTAL LABOR		MAT'LS	TOTAL OF LABOR & MAT'LS
		›ST	HOURS	COST	HOURS	COST	COST	
24"	C.L	[illegible]	.2	$0.04	4.3	$.60	$	$
·	AL	.04	.3	.08	4.7	1.27	.60	1.87
"		.10	.7	.14	10.6	2.59	.62	3.21
·	Com	.277	.47	.108	4.1	1.10	.20	1.30
·	13	.294	.4	.122	4.9	1.352	.314	1.67
"	10T	.47	.3	.14	6.8	1.85	.15	2.00
"	C.L		.2	.09	2.5	.90		
"	AL	.10	.9	.21	11.0	2.65	.59	3.24
30		.18	1.4	.30	7.4	1.97	.67	2.64
"		11	1.3	.22	11.6	3.15	.79	3.85
"		10	1.6	.14	13.3	3.36	.70	4.36
30	C.L	.10	.5	.11	5.3	1.58		
"		.19	.02	.04	6.0	1.50		
"		.22	.6	.01	3.8	1.24	.06	1.30
"		.17	.2	.03	6.3	1.48		
"	AL	10	1.3	.30	10.8	2.79	.75	3.64
"	C.L	.21	.3	.06	6.2	1.71		
"	13	.14	.8	.20	7.9	2.38	.46	2.74
·	Ho	.22	.4	.15	4.8	1.43	.34	1.77
"		.10	.5	.12	6.6	2.32	.72	3.04
42	12	.12	.5	.14	8.3	2.57	.87	3.44
·	Al	.10	1.9	.57	7.5	2.09	.48	2.57
48		.18	.4	.16	10.3	2.72	.83	3.55
·	BL		.6	.15	3.8	1.13		
54	13	.68	1.1	.26	21.5	5.47		
"		.17	.3	.11	6.0	2.23		
"	Al	.24	.9	.27	18.7	4.82	1.04	5.86
"		.54	1.0	.27	13.7	3.74	1.19	4.93
57	C.		.5	.18	2.4	.81	.71	1.52
60	OP		1.8	.53	14.4	3.48		
"		.26	1.9	.46	18.0	4.11	1.20	5.31
63	C.		.5	.19	3.0	1.08	.88	1.96
66			.9	.26	3.9	1.35	1.26	2.61
72	M	.13	.1	.03	7.5	2.21		
"	B	.45	.3	.17	11.4	3.56		
"	M	.05	.8	.25	9.0	2.72		
"	M	2.8	1.6	.71	17.0	4.65		
	A							

T

COMPLETE COST OF TRENCHING PER LINEAL FOOT OF SEWER. 8. 1907-09.

LOCATION		LENGTH	SOIL	PUMPING	DEPTH	HARD DIGGING		SCRAPER DIGGING		MACHINE DIGGING		SHEETING & BRACING		PUMPING		BACK-FILLING		TOTAL LABOR		MAT'LS	TOTAL OF LABOR & MAT'LS
						HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	COST	
24"	C.L.S.&E.RY. KIRK YD.	4200	SAND	T.P.	6.4	2.6	$0.55					1.3	$.30	.2	.10	.2	$0.04	4.3	$.60	$	$
"	ALLEY 3 GARY	695	"	"	7.8	3.0	.76					1.3	.39	.1	.04	.3	.08	4.7	1.27	.60	1.87
"	" 13 "	335	"	"	8.0	5.8	1.21	.6	.25			3.1	.89	4	.10	.7	.14	10.6	2.59	.62	3.21
"	COMMERCIAL AV. HEGEWISCH	1336	"	POINTS	9.7	1.9	.524					.68	.189	1.05	.277	.47	.108	4.1	1.10	.20	1.30
"	136 ST "	581	"	"	10.0	2.4	.65					1.0	.284	1.1	.294	.4	.122	4.9	1.352	.314	1.67
"	10TH AVE. GARY	936	"	T.P.& "	11.7	2.8	.60	.5	.17			1.6	.47	1.6	.47	.3	.14	6.8	1.85	.15	2.00
"	C.L.S.&E.RY KIRK YARD	510	"	NONE	12.0	1.2	.32	.6	.29			.5	.20			.2	.09	2.5	.90		
"	ALLEY 7 GARY	710	"	T.P.	14.7	6.8	1.42	.5	.24			2.4	.69	.4	.10	.9	.21	11.0	2.65	.59	3.24
30	" 26 "	855	"	"	11.3	2.8	.81			.6	.184	2.0	.50	.6	.18	1.4	.30	7.4	1.97	.67	2.64
"	" 7 "	365	"	"	14.5	7.0	1.90	.4	.18			2.7	.75	2	11	1.3	.22	11.6	3.15	.79	3.85
"	" 13 "	367	"	"	15.1	8.1	1.83	1.0	.42			3.2	.87	4	10	1.6	.14	13.3	3.36	.70	4.36
36	C.L.S.&E.RY. KIRK YD.	216	"	"	3.6	2.4	.60					2.0	.77	.4	.10	.5	.11	5.3	1.58		
"	" PINE	705	"	"	6.0	3.5	.71	.2	.10			1.4	.46	.9	.19	.02	.04	6.0	1.50		
"	" "	253	"	"	7.0	1.6	.42					1.6	.49	.6	.22	.6	.01	3.8	1.24	.06	1.30
"	" KIRK YD	1800	"	"	7.1	3.6	.82					2.0	.45	.5	.17	.2	.03	6.3	1.48		
"	ALLEY 26 GARY	1090	"	"	7.3	4.2	.97			1.1	.34	4.0	1.08	.2	10	1.3	.30	10.8	2.79	.75	3.64
"	C.L.S.&E. CLARK-PINE	3268.5	"	"	9.0	3.4	.80		.19			1.7	.44	.8	.21	.3	.06	6.2	1.71		
"	134TH ST. HEGEWISCH	653	"	"	9.5	3.5	1.02			.3	.16	2.9	.86	.4	.14	.8	.20	7.9	2.38	.46	2.74
"	HOWARD AV. I,	932	"	POINTS	11.0	2.9	.81			.13	.07	.6	.19	.8	.22	.4	.15	4.8	1.43	.34	1.77
"	" "	1700	"	"	11.4	1.8	.50			.15	.78	2.3	.83	.5	.10	.5	.12	6.6	2.32	.72	3.04
42	124TH ST. "	1657	"	"	12.0	4.2	1.14			1.0	.54	2.1	.64	.5	.12	.5	.14	8.3	2.57	.87	3.44
"	ALLEY 26 GARY	330	"	"	17.2	2.3	.53			.7	.21	2.4	.68	.3	.10	1.9	.57	7.5	2.09	.48	2.57
48	" "	1325	"	"	14.0	4.8	1.19			1.1	.34	3.4	.85	.6	.18	.4	.16	10.3	2.72	.83	3.55
"	BL. FCES. IND. STEEL CO	894.2	"	"	14.6	2.1	.39	.9	.50			.2	.09			.6	.15	3.8	1.13		
54	134TH ST HEGEWISCH, W.	373	"	"	12.0	13.0	3.18					4.9	1.35	2.5	.68	1.1	.26	21.5	5.47		
"	" " E.	293.	"	"	12.7	1.8	.53			1.1	.64	2.3	.76	.5	.17	.3	.11	6.0	2.23		
"	ALLEY 20 E. GARY	1328	"	"	19.4	11.9	2.80			1.6	.44	3.4	1.07	.9	.24	.9	.27	18.7	4.82	1.04	5.86
"	" W. "	2035	"	"	21.9	7.2	1.75			1.2	.40	3.6	.93	1.4	.54	1.0	.27	13.7	3.74	1.19	4.93
57	C.U.T. CLEARING ILL	26954	CLAY	NONE	12.2	.4	.19			.5	.19	1.0	.26			.5	.18	2.4	.81	.71	1.52
60	OPEN HEARTH IND STEEL CO.	461.5	SAND	T.P.	16.7	7.8	1.40	1.4	.79			3.4	.77			1.8	.53	14.4	3.48		
"	" "	415.	"	"	19.3	10.5	2.12	1.4	.67			2.9	.60	1.2	.26	1.9	.46	18.0	4.11	1.20	5.31
63	C.U.T. RY. CLEARING ILL	2663.3	CLAY	NONE	13.7	.6	.23			.7	.32	1.2	.34			.5	.19	3.0	1.08	.88	1.96
66	" "	1882.3	"	"	16.7	.5	.29			.9	.41	1.4	.38			.9	.26	3.9	1.35	1.26	2.61
72	MILL SEWER IND. STEEL CO.	576.5	SAND	T.P.	12.8	3.7	.74	1.1	.79			2.1	.52	.5	.13	.1	.03	7.5	2.21		
"	BL. FCE "	275.5	"	"	15.2	6.6	1.37	1.3	.77			2.8	.80	1.4	.45	.3	.17	11.4	3.56		
"	MILL "	1910.	"	"	16.0	5.6	1.49					2.8	.93		.05	.8	.25	9.0	2.72		
"	MERCHANT MILL "	1213.75	"	"	19.7	4.1	1.88	1.2	1.01			4.7	.76	1.0	.28	1.0	.71	17.0	4.65		
	AVERAGES	41837.																			

TOTAL OF ALL 72794. = 13.8 MILES.

9. 1907-09.

COARTH DUG.

BY TOTAL YARDAGE

SIZE OF SEWER	UMPING		BACK FILLING		TOTAL LABOR		COST OF MAT'LS	TOTAL OF LABOR & MAT'LS
	URS	COST	HOURS	COST	HOURS	COST		
FOUNDATION	8	.25	.6	.165	3.8	1.23	.15	1.38
"						.2		
"								
2'8"×1'-10"	6	.113			2.1	.40	.02	.42
2'0"×3'-0"					1.2	.27	NONE	.27
8"			.4	.07	1.0	.20	"	.20
"	.05	.01			.45	.20	"	.20
10"			.6	.10	2.6	.60	"	.60
"					.7	.37	"	.37
12	.1	.02			1.3	.34		
"				.21		.79		
"				.21		.425		
"			.1	.03	.8	.22		
"	.7	.16	.05	.05	1.7	.42	.19	.61
"	.47	.13	.3	.10	2.15	.617	.12	.648
"	.55	.143	.45	.098	1.9	.504	.138	.642
"	.44	.115	.24	.088	1.93	.572	.10	.672
"	1.1	.32	.6	.14	3.6	.95	.18	.641
"	.56	.144	.03	.02	1.28	.317	.097	.414
"	.55	.15	.27	.06	1.93	.511	.077	.588
"	N EXCAV'N			.01	2.7	.64	.074	.714
"	.6	.165	.35	.08	2.1	.57	.10	.67
"	.8	.21	.3	.09	2.5	.75	.227	.978
"	.8	.20	.3	.07	2.7	.69	.073	.763
"	.6	.157	.6	.108	2.5	.59	.085	.673
15"	.7	.195	.3	.065	2.2	.565	.082	.647
"	.64	.17	.7	.14	2.9	.695	.07	.805
"	.6	.172	.2	.075	1.87	.563	.12	.683
"	.3	.102	.2	.05	1.62	.46	.086	.546
"	.6	.164	.2	.04	2.3	.564	.10	.664
"	.5	.12	.1	.03	2.0	.555	.096	.651
18"	.45	.21	.3	.10	2.55	.765	.175	.94
"		.04	.3	.09	1.2	.772	.029	.927
"	.15	.03	.13	.04	3.5	1.02	.05	1.07
"	.6	.185	.13	.04	1.8	.58	.048	.233
"	.8	.195	.6	.139	3.2	.811	.101	.912
"	.6	.15	.2	.044	2.1	.60	.10	.70
"	.1	.03	.2	.06	2.4	.585		
	.1	.04	.8	.03	1.6	.64	.06	.70
20	.1	.055	.3	.09	3.5	.81	.02	.85
T.P. = ANLY.								
POINT								

732^{9}

COMPLETE EXCAVATION OR "TRENCHING" COST PER CU. YARD OF EARTH DUG.

9. 1907-09.

ALL COSTS BEING DIVIDED BY TOTAL YARDAGE

SIZE OF SEWER	LOCATION	DATE	SOIL	PUMPING	DEPTH	HAND DIGGING		SCRAPER DIGGING		MACHINE DIGGING		SHEETING & BRACING		PUMPING		BACK FILLING		TOTAL LABOR		COST OF MAT'LS	TOTAL OF LABOR & MAT'LS
						HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST		
FOUNDATION	WATER TOWER GARY	OCT '07	SAND	T. P.	8.0	2.0	$.59					.4	.22	8	.25	.6	.165	3.8	1.23	.15	1.38
"	CH'GO. D. F. & F'DY CO. CHICAGO	MAR. 10	CLAY.	" +															.2		
"	IROQUOIS IRON CO. PIT	APR '10	HARD SLAG.	"																	
2'8"x1'-10"	BOX FLUME GARY	" '08	SAND.	" +	8.0	1.3	.24					.2	.05	.6	.113			2.1	.40	.02	.42
2'-0"x3'-0"	" HEGEWISCH	JU '09	CLAY SAND.	" +	2.5	1.2	.27											1.2	.27	NONE	.27
8"	L S M. S. RY PINE IND.	OCT '08	SAND	NONE	5.0	.6	.13									.4	.07	1.0	.20	"	.20
"	C. L. S. & E. RY KIRK YARD	JUNE '08	"	T. P. +	5.7	.4	.19					.4	.107	.05	.01			.45	.20	"	.20
10"	" "	" "	"	NONE	4.4	1.7	.38					.4	.12			.6	.10	2.6	.60	"	.60
"	REYNOLDS B'LD'G GARY	SEPT. '08	"	NONE	8.0	.7	.37											.7	.37	"	.37
12	C. L. S. & E. RY. KIRK YARD	JUNE '08	"	T. P. +	7.5	1.0	.24	.2	.08			.7	.18	.1	.02			1.3	.34		
"	ALLEY 8 GARY	APR. '09	"	NONE	8.0	1.5	.33					.9	.25				.21		.79		
"	" 9 "	"	"	"	9.4	9	.21	.35	.145			.2	.07				.21		.425		
"	" 10 "	"	"	"	11.4	1.0	.22	.35	.147			.6	.15			.1	.03	.8	.22		
"	BUFFALO AV HEGEWISCH	SEPT '10	"	POINTS	6.5	.7	.20					.01	.003	.7	.16	.05	.05	1.7	.42	.19	.61
"	CARONDELET AV "	"	"	"	6.7	1.2	.35					.12	.035	.47	.13	.3	.10	2.15	.617	.12	.648
"	ERIE AV. "	OCT. '10	"	"	6.9	.7	.19					.20	.071	.55	.143	.45	.098	1.9	.504	.138	.642
"	HOUSTON AV "	"	"	"	7.5	1.02	.303					.21	.07	.44	.115	.24	.088	1.93	.572	.10	.672
"	ONTARIO " "	"	"	" & +	7.5	1.5	.36					.77	.13	1.1	.32	.6	.14	3.6	.95	.18	.641
"	SUPERIOR " " N.	NOV. '10	"	POINTS	9.5	.63	.14					.08	.02	.56	.144	.03	.02	1.28	.317	.097	.414
"	" " " S.	"	"	"	9.8	.8	.23					.25	.07	.55	.15	.27	.06	1.93	.511	.077	.588
"	HOUSTON " " S.	SEPT. '10	"	T. P.	10.0	2.2	.50					.42	.13	IN EXCAV'N			.01	2.7	.64	.074	.714
"	ONTARIO " " S	NOV. '10	"	POINTS	"	.9	.265					.2	.06	.6	.165	.35	.08	2.1	.57	.10	.67
"	HOUSTON " " S	OCT. '10	"	"	"	1.1	.364					.28	.083	.8	.21	.3	.09	2.5	.75	.227	.978
"	BUFFALO " " S	NOV. '10	"	"	10.5	1.3	.31					.3	.11	.8	.20	.3	.07	2.7	.69	.073	.763
"	ERIE " " S	OCT. '10	"	"	11.0	1.2	.27					.2	.055	.6	.157	.6	.108	2.5	.59	.085	.673
15"	BUFFALO " "	NOV. '10	"	"	8.2	.9	.22					.3	.085	.7	.195	.3	.065	2.2	.565	.082	.647
"	ONTARIO " "	"	"	"	9.2	1.25	.332					.16	.055	.64	.17	.7	.14	2.9	.695	.07	.805
"	HOUSTON " "	OCT. '10	"	"	8.3	.77	.219					.34	.096	.6	.172	.2	.075	1.87	.563	.12	.683
"	CARONDELET " "	SEPT. '10	"	"	9.2	.95	.235		.01			.2	.061	.3	.102	.2	.05	1.62	.46	.086	.546
"	SUPERIOR " "	NOV. '10	"	"	9.5	1.3	.301					.24	.06	.6	.164	.2	.04	2.3	.564	.10	.664
"	ERIE " "	OCT. '10	"	"	10.0	1.3	.35					.18	.053	.5	.12	.1	.03	2.0	.555	.096	.651
18"	HOUSTON " "	"	"	"	9.5	1.25	.35					.31	.10	45	.21	.3	.10	2.55	.765	.175	.94
"	" " "	SEPT. '10	"	T. P.	10.0	.86	.192					1.36	.45		.04	.3	.09	1.2	.772	.029	.927
"	CARONDELET " "	"	"	"	10.5	3.9	1.02	.46	.187			1.08	.35	.15	.03	.13	.04	3.5	1.02	.05	1.07
"	" " "	"	"	POINTS	"	.95	.31	.47	.187			.35	.104	.6	.185	.13	.04	1.8	.58	.048	.233
"	ONTARIO " "	NOV. '10	"	"	"	1.5	.408					.3	.069	.8	.195	.6	.139	3.2	.811	.101	.912
"	ERIE " "	OCT. '10	"	"	11.0	1.2	.324					.29	.085	.6	.15	.2	.044	2.1	.60	.10	.70
"	C. L. S. & E. RR. PINE IND.	JUNE '08	"	T. P.	6.8	1.6	.38					.5	.12	.1	.03	.2	.06	2.4	.585		
	" KIRK YARD	OCT. NOV. '07	"	"		1.9	.65	CONTR.	.20			.6	.21	.1	.04	.8	.03	1.6	.64	.06	.70
20	ALLEY 8 GARY IND.	MAY '08	SAND & MUCK	"	15'	3.1	.607	.35	.167			1.0	.24	.1	.055	.3	.09	3.5	.81	.02	.85

T. P. = PUMPING FROM TRENCH WITH SUCTION HOSE (TO STEAM PUMP) IN THE TRENCH + = HAND PUMPING ONLY.
POINTS = " BY WELL POINTS BEFORE WATER ENTERS TRENCH, GIVING AN ENTIRELY DRY TRENCH

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COMARTH DUG. 1907-09.

DIVIDED BY TOTAL YARDAGE DUG. FOR EACH ITEM

SIZE OF SEWER		PING.	BACKFILLING		TOTAL LABOR		COST OF MAT'LS	TOTAL OF LABOR & MAT'LS	
		COST	HOURS	COST	HOURS	COST.			
24"	C.L.	.054			4.1	$0.899	$ .10	$0.999	
"	AL	.02	.2	.05	3.4	.87	.03	0.90	
"		.05	.1	.03	3.7	.922	.02	0.942	
"	COMP	.17	.3	.067	2.53	.678	.125	0.803	
"	136	.16	.2	.066	2.5	.731	.171	0.902	
"	10	.48	.4	.14	6.97	2.42	.156	2.576	
"	C.L.		.1	.06	1.7	.59		0.59	
"	ALL	.04	.4	.06	3.3	.795	.18	0.975	
30	"	.24	1.6	.33	2.0	.61	19	0.80	
"	"	.08	.4	.07	3.5	0.90	.20	1.10	
"	"	.04	.7	.17	3.0	0.78	.085	0.865	
36	C.L.	.30	.5	.13	5.8	1.70			
"		.056	.07	.013	1.8	.45			
"	5	.068	.3	.076	3.57	1.054	C.I. PIPE UNDER 7 RR TRACKS		
"		.12	2	.034	4.6	1.06			
"	ALL	.02	.24	.05	19	.47	.13	60	
"	C.L.	.875	.13	.026	2.7	.725			
"	134	.058	.3	.092	3.5	1.035	.196	1.231	
"	HOW	.08	.2	.037	1.8	.51	.13	.64	
"		.035	.2	.048	2.6	93	.29	1.22	
42	13	.043	.2	.05	3.0	.941	.317	1.26	
"	ALL	.004	.28	.083	1.2	.32	.08	.40	
48		.082	.1	.031	2.0	.52	.17	.69	
"	BL.F								
54	134	.215	.35	.08	6.7	1.69	.525	2.43	UNDER 6 TRACKS!
"	"	.06	1	.04	2.1	.80	.32	1.12	
"	ALL	.07	.1	.04	2.1	.56	.11	.67	
"		.15	.03	.024	1.4	.36	.11	.47	
57	C.I.T		.13	.052	.67	.226	.197	.423	
60	OPEN	.03	.26	.06	2.1	.48	.14	.62	
"		.056	.45	.10	2.2	526			
63	C.U.		16	06	.55	.233	.19	.423	
66			.16	.06	77	.28	.233	.413	
72	MIL	.014	.31	.31	2.7	.71			
"	BL.	.063	.07	.025	1.73	.49			
"	MI	.015	–	.005	1.0	328			
"	MER	.05	.16	.14	2.9	.76			
	A	$0.12	3	$0.08	2.7	$0.75	$ 18	$0.93	

COMPLETE EXCAVATION OR "TRENCHING" COST PER CU. YD. OF EARTH DUG.

10

1907-09.

ALL COSTS BEING DIVIDED BY TOTAL YARDAGE DUG, FOR EACH ITEM

SIZE OF SEWER	LOCATION	DATE	SOIL	PUMPING.	DEPTH	HAND DIGGING.		SCRAPER DIGGING		MACHINE DIGGING.		SHEETING & BRACING		PUMPING.		BACKFILLING		TOTAL LABOR		COST OF MAT'LS	TOTAL OF LABOR & MAT'LS	
						HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST.			
24"	C.L.S.&E.Ry Kirk Yard	Apr '08	Sand	T.P.	6.4	2.6	$.545					1.3	.30	.2	.054			4.1	$.899	$ .10	$0.999	
"	Alley 3 Gary	Aug. '07	"	"	7.8	2.0	.53					1.0	.27	.2	.02	.2	.05	3.4	.87	.03	0.90	
"	" 13 "	June "	"	"	8.0	2.1	.44	.5	.182			.8	.22	.2	.05	.1	.03	3.7	.922	.02	0.942	
"	Commercial Av. Hegewisch	Oct '09	"	Points	9.7	1.15	.324					.43	.117	.65	.17	.3	.067	2.53	.678	.125	0.803	
"	136th St. "	"	"	"	10.0	1.25	.352					.51	.158	.54	.16	.2	.066	2.5	.731	.171	0.902	
"	10th Av. Gary	Mar '09	"	T.P. "	11.7	2.8	.61	.35	.13			1.6	.46	1.72	.48	.4	.14	6.97	2.42	.156	2.576	
"	C.L.S.&E.Ry. Kirk Yard		"	None	12.0	(Total	1.2 Hr	$0.406	→)			.4	.124			.1	.06	1.7	.59		0.59	
"	Alley 7 Gary	July '07	"	T.P.	14.7	3.4	.72	.4	.18			.6	.20	.2	.04	.4	.06	3.3	.795	.18	0.975	
30	" 26 "	" "	"	"	11.3	3.6	1.05			.22	.066	.55	.14	8	.24	1.6	.33	2.0	.61	19	0.80	
"	" 7 "	" "	"	"	14.5	3.3	89	.4	.16			76	.21	.26	.08	.4	.07	3.5	0.90	.20	1.10	
"	" 13 "	June "	"	"	15.1	4.4	1.01	.4	.16			.7	.20	.2	.04	.7	.17	3.0	0.78	.085	0.865	
36	C.L.S.&E.Ry Kirk Yard	" '08	"	"	3.6	2.1	.59					2.2	.68	1.0	.30	.5	.13	5.8	1.70			
"	" Pine Ind.	Oct. 08	"	"	6.0	1.25	.27	.33	.16			.42	.138	.27	.056	.07	.013	1.8	.45			
"	" "	Sept '08	"	"	7.0	1.62	.40					1.4	.51	.25	.068	.3	.076	3.57	1.054	C.I. Pipe under 2 RR	Tracks	
"	" Kirk Yard	Mar. '08	"	"	7.1	2.6	.59					1.4	.32	.4	.12	2	.024	4.6	1.06			
"	Alley 26 Gary	July '07	"	"	7.3	2.6	.623			.25	077	.65	.18	.2	.02	.24	.05	19	.47	.13	.60	
"	C.L.S.&E. Clark-Pine	July '08	"	"	9.0	3.63	.76		.16			.73	.19	3.6	.875	.13	.026	2.7	.725			
"	134th St. Hegewisch	Sept. '09	"	"	9.5	1.2	.45			.5	.068	1.24	.372	.2	.058	.3	.092	3.5	1.035	.196	1.231	
"	Howard Av. "	Oct. '09	"	Points	11.0	1.1	.30			1.0	.06	.22	.067	.3	.08	.2	.037	1.8	.51	.13	.64	
"	" "	"	"	T.P.	11.4	2.4	.65			.82	.45	.94	.328	.2	.035	.2	.048	2.6	93	.29	1.22	
42	134th St. "	Aug '09	"	"	12.0	1.5	.42			.39	.19	.75	.23	.16	.043	.2	.05	3.0	.941	.317	1.26	
"	Alley 26 E Gary	June '07	"	"	17.2	1.4	.32			.2	.05	.4	.11	.02	.004	.28	.083	1.2	.32	.08	.40	
48	" " W. "	July "	"	"	14.0	2.1	.52			.4	.12	.68	.17	08	.082	.1	.031	2.0	.52	.17	.69	
"	Bl. Fces Indiana Steel Co.	May '08	"	"	14.6	Yardage Costs Not Kept.																
54	134th St. W. Hegewisch	Aug. '09	"	"	12.0	4.0	.98					1.5	.42	.78	.215	.35	.08	6.7	1.69	.525	2.43	under 6 tracks)
"	" E "	" "	"	"	12.7	.6	.19			.4	.24	.8	.27	.2	.06	.1	.04	2.1	.80	.32	1.12	
"	Alley 20 E. Gary	Aug '07	"	"	19.4	4.75	1.11			.22	.062	.36	.11	.4	.07	.1	.04	2.1	.56	.11	.67	
"	" W. "		"		21.5	2.5	.71			.33	.047	.32	.08	.34	.10	.03	.024	1.4	.36	.11	.47	
57	C.M.T. Ry. Clearing Ill.	Oct. '08	Clay	None	12.2	2.1	.86			.15	.054	.27	.07			.13	.052	.67	.226	.197	.423	
60	Open Hearth Ind. St. Co.	Apr. '08	Sand	T.P.	16.7	2.4	.50	.3	.156			.34	.69	.15	.03	.26	.06	2.1	.48	.14	.62	
"	" "	Aug "	"	"	19.3	3.1	.55	.28	.16			.45	.10	.27	.056	.45	.10	2.2	526			
63	C.U.T. Ry Clearing Ill.	Sept. '08	Clay	None	13.7	1.9	.77			.17	.07	.26	.07			16	06	.65	.233	.19	.423	
66	" "	" "	"	"	16.7	3.0	1.29			.17	08	.26	.07			.16	.06	77	.28	.233	.413	
72	Mill Sewer Ind. Steel Co.	July-Dec '07	Sand	T.P.	12.8	2.9	.76	.28	.16	.34	.11	.30	.10	.06	.014	.31	.31	2.7	.71			
"	Bl. Fce. "	Sept '08	"	"	15.2	2.7	.55	.27	.16			38	.11	.18	.063	.07	.025	1.93	.49			
"	Mill "	" "	"	"	16.0	2.2	.43	.2	.16			.31	.08	.05	.015	–	005	1.0	328			
"	Merchant Mill "	Oct. '08	"	"	19.7	1.4	.30	.2	.16			.43	.12	.2	.05	.16	.14	2.9	.76			
	AVERAGES					2.4	$0.60	.33	$0.16	.37	$0.12	.7	$0.22	.5	$0.12	3	$0.08	2.7	$0.75	$ .18	$0.93	

11.

1907-09

Cost Per Line

	C				
Diameter	4'·0"	4	4'·6"	5'·0"	6'·0"
Conc. Labor	$ 0.74	$			
Brick "			1.68	$ 1.80	$ 1.94
Materials.					
Cement	44		.24	.28	.33
Sand	16		.08	.10	11
Stone	.26				
Brick			1.40	1.53	1.78
Total Mat'l's	.86		1.72	1.91	2.22
" Cost	1.60		3.40	3.85	4.16
Brick at $7.00			1.65	1.78	2.07
Total Mat'l's			1.97	2.16	2.51
" Cost			3.65	3.96	4.45
Quantities					
Cement Bbl.	.34		.37	.43	.50
Sand Cu. Yd.	.15		.092	108	124
Stone Cu. Yd.	29				
Brick Car count			2330	2550	2960
Masonry per Ft. Cu. Yd.	.36		.43	.50	58
Thickness of wall	8"				
	Concre		ement		

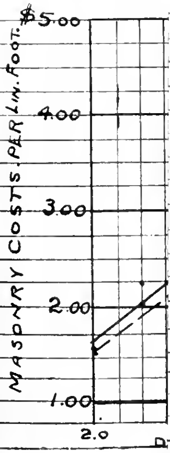
In brickwork in a sandy locality the sand of the trench was found suitable for mortar in such cases deduct item for sand cost.

Costs given here vary somewhat on account of the work done covers 3 years with varying labor & mat'ls.

Brick ranged from $5.00 to $6.00 per M. on cars

Portland cement $1.00 to $1.20 per bbl.

Etc.



1910)

332

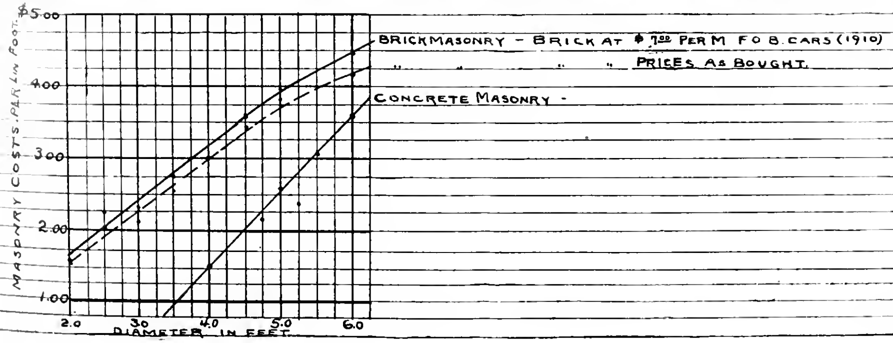
11.
1907-09

COST PER LINEAL FOOT OF CONCRETE & BRICK SEWER MASONRY.

	CONCRETE						BRICK							
DIAMETER	4'-0"	4'-9"	5'-0"	5'-3"	5'-6"	6'-0"	2'-0"	2-6"	3'-0"	3'-6"	4'-0"	4'-6"	5'-0"	6'-0"
CONC LABOR	$0.74	$1.00	$1.23	$1.06	$1.39	$1.51								
BRICK "							$0.73	$1.01	$0.97	$1.19	$1.21	$1.68	$1.80	$1.94
MATERIALS														
CEMENT	44	.60	.71	.66	.85	1.02	.11	.14	.16	.22	.21	.24	.28	.33
SAND	16	.21	.25	24	30	36	.04	.05	.06	.08	.07	.08	.10	11
STONE	.26	.35	.41	.39	.50	.60								
BRICK							.69	.90	.94	1 4	1.28	1.40	1.53	1.78
TOTAL MAT'L'S	.86	1.16	1.37	1.29	1.65	1.98	.84	1.09	1.16	1.34	1.56	1.72	1.91	2.22
" COST	1.60	2.16	2.60	2.35	3.04	3.59	1.57	2.10	2.13	2.53	2.77	3.40	3.85	4.16
BRICK AT $7.00							.80	1.05	1.10	1.27	1.50	1.65	1.78	2.07
TOTAL MAT'L'S							1.95	1.24	1 32	1.57	1.78	1.97	2.16	2.51
" COST							1.68	2.25	2.29	2.76	2.99	3.65	3.96	4.45
QUANTITIES														
CEMENT BBL.	.34	.54	.61	.43	.77	.70	.17	.22	.24	.34	.32	.37	.43	.50
SAND CU.YD.	.15	.19	.23	22	27	.33	.042	.055	.06	.085	.08	.092	108	124
STONE CU.YD.	29	39	.46	.43	.55	.66								
BRICK CAR COUNT							115.0	149.0	157.0	181.0	214.0	233 0	255.0	296.0
MASONRY PER FT. CU.YD.	.36	.48	.57	.53	.68	.82	.22	.29	.31	.36	.42	.43	.50	58
THICKNESS OF WALL	8"	8"	10"	9"	9"	12"	TWO RINGS OR 8¾ INCHES.							
	CONCRETE MIXTURE 1:3:5 AND 1:3:6						MORTAR 1:3 "UTICA" NATURAL CEMENT.							

IN BRICKWORK IN A SANDY LOCALITY THE SAND OF THE TRENCH WAS FOUND SUITABLE FOR MORTAR IN SUCH CASES DEDUCT ITEM FOR SAND COST.

COSTS GIVEN HERE VARY SOMEWHAT ON ACCOUNT OF THE WORK DONE COVERS 3 YEARS WITH VARYING LABOR & MAT'LS.
BRICK RANGED FROM $5.00 TO $6.00 PER M. ON CARS
PORTLAND CEMENT $1.00 TO $1.20 PER BBL.
ETC.



36" CIRCULAR

CONSTRUCTION COSTS. JULY-AUG 1908.

12.

ITEMS	COST	PER UNIT	PER LIN. FT	TOTAL PER UNIT	TOTAL PER LIN. FT. OF SEWER
EXCAVATION BY SCRAPERS HAND MAKING DAMS PUMPING					
TOTAL					
SHEETING & BRACING PLACING PULLING JET PUMPING	T FOR D SOME BLY				
TOTAL					
BACKFILLING HAND WORK					
TRENCHING TOTAL					
MASONRY BRICK HAULING CEMENT " STEAM PUMPING HAND " BRICKLAYERS " HELPERS MORTAR MEN FORMS	 1319.00 570.00 43.00 154.20				
TOTAL					
GENERAL CLEANING UP " SEWER WATCHMEN SHIPPING IN & OUT TOOLS, MCHY. SHEETG ETC. SUPERINTEND'CE					
TOTAL.					
TOTAL					

BRICKLAYER PER 8 HR. DAY
4972 BRICK
10.7 CU. YDS
33.0 LIN FT.
150.8 BRICK PER FOOT.

LABOR SCARCE & DIFFICULT TO GET - AS THE WORK WAS 3½ TO 4 MILES FROM GARY WITH INFREQUENT TRAINS AND HEAT IN THE SWAMPY DENSE THICKETS WAS INTENSE

CEMENT HAULED BY CONTRACT 10¢ PER BBL. 5/8 MILE HAUL. SAND ROAD.

SCRAPER WORK DONE BY CONTRACT AT $0.15 PER CU. YD. ON 3732.4 CU. YDS. WORK

DEPTH	SCRAPE
MAX	23.0
MIN	0.0
AVE	4.4
WIDTH	8.0
VOL. PER FOOT	1.3

THE SHEETING REQUIRED
18 FT. B.M.

COST PER FOOT "DRIVING"
1.02 H'RS $ 0.282
PER M' B.M. 17.9 H'RS. $4.95
TOTAL PER FOOT 1.784 HRS. $0.492
" M. FT. B.M. 31.3 - 8.63

THE EXPENSE WAS

124 DAYS TEAMS	$620.00
30 " SLIPHOLDER	60.00
12 " GRUBBER	24.00
TOTAL.	704.00

30.1 YDS. PER 10 HR. DAY PER TEAM $0.159 PER CU. YD

36" CIRCULAR BRICK SEWER CL.S.&E.R.R.Co.
CLARKE - PINE IND. NASH-DOWDLE CO.
CONTRACTOR CONSTRUCTION COSTS. JULY-AUG 1908.

12.

ITEMS	LABOR COSTS HOURS	 COST $	WORK DONE, 3268.5'	LABOR PER MAN PER HOUR	UNIT OF WORK HOURS	 COST	FOOT OF SEWER HOURS	 COST	MATERIALS ITEMS	 QUANTITIES	 PRICES	 COST	PER UNIT	PER LIN. FT.	TOTAL PER UNIT	 LIN. FT. OF SEWER.
EXCAVATION BY						$		$								
SCRAPERS	NO RECORD	642 90	4286 Cu. Yds.	—	—	0.16	—	19								
HAND	12553	2636.30	3460 "	.21	.	76	3.4	80	TOOLS	?						
MAKING DAMS	"858	159.50		.185	-	-	3	.05								
PUMPING	741	218.40		.29	-	-	.12	.07								
TOTAL	13152	3657.10	7746	.28		.473	3.9	1.12								
SHEETING & BRACING					PER M'	B.M.			NO NEW SHEETING WAS BOUGHT FOR THIS WORK - THE SHEETING USED SOME OF IT HAVING BEEN USED PROBABLY 12 OR 15 TIMES							
PLACING	3824	992 50	214,410' B.M.	.26	18.0	4.62	1.1	30								
PULLING	1358	330.20		.245	6.7	1.58	.4	.10								
JET PUMPING	405	121.50		.30	1.9	.55	.2	.04								
TOTAL	5687	1444.20	3460 Cu. Yds.	.254	26.6	6.75 0.42) Cu. Yd.	1.7	.44								
BACKFILLING / HAND WORK	980	204.65		.21		.06	3	.06								
TRENCHING TOTAL	19819	5305.95		217	4.6	0.69	5.9	1.62								
MASONRY																
BRICK HAULING		785.28	HAULED BY CONTRACT AT $1.60 PER M			.75	..	.24	BRICK	493,544	4.70	2319.00				
CEMENT "		98.00				.09	..	.03	CEMENT	475 BBLS.	1.20	570.00				
STEAM PUMPING	741	218.40	1060 Cu. Yds.	.30	.70	.21	.2	.07	" SACKS	430	0.10	43.00				
HAND "	441	80.70		.183	.39	07	.1	.02	COAL	51.4 TONS	3.00	154.20				
BRICKLAYERS	794	952.50	BRICKWORK	1.25	.75	.90	.3	.29	TOOLS	?						
" HELPERS	1818	450.10	0.324 Cu. Yd.	248	1.7	.42	.6	.14	SUPPLIES	?						
MORTAR MEN	1545	350.00	PER FT.	227	1.5	.33	.6	.11								
FORMS	1160	315.85		.27	1.1	.30	.4	.10								
TOTAL	6499	3250.73		.50	6.14	3.07	2.2	1.00								
GENERAL																
CLEANING UP	473	174.30		.37				.05								
" SEWER	30	10.60		.35												
WATCHMEN	510	91 85		18			.4	.03								
SHIPPING IN & OUT TOOLS, MCH'Y, SHEET'G ETC.	555	204.10		37				.06								
SUPERINTEND'CE	1161	873.60		75			.4	.27								
TOTAL	2729	1354.45		.50			.8	41								
TOTAL	29047	9911.13		.224			8.9	3.03								

BRICKLAYER PER 8 HR. DAY
4972 BRICK
10.7 CU. YDS
33.0 LIN FT.
150.8 BRICK PER FOOT.

LABOR SCARCE & DIFFICULT TO GET - AS THE WORK WAS 3½ TO 4 MILES FROM GARY WITH INFREQUENT TRAINS AND HEAT IN THE SWAMPY DENSE THICKETS WAS INTENSE

CEMENT HAULED BY CONTRACT 10¢ PER BBL. 5/8 MILE HAUL. SAND ROAD.

SCRAPER WORK DONE BY CONTRACT AT $0.15 PER CU. YD. ON 3732.4 CU. YDS. WORK

DEPTH	SCRAPER	HAND	TOTAL
MAX	23.0	8.0	25.0
MIN	0.0	0.0	0.0
AVE	4.4	4.63	9.03
WIDTH	8.0	5.7	" "
VOL. PER FOOT	1.3	1.1	2.4 Cu. Yds.

SHEETING 2"×8"-12'0"
STRINGERS 2 SETS 3"×12"-16'0
BRACES 6"×6" 5'4" ¢ TO ¢
SHEETING JETTED IN PLACE

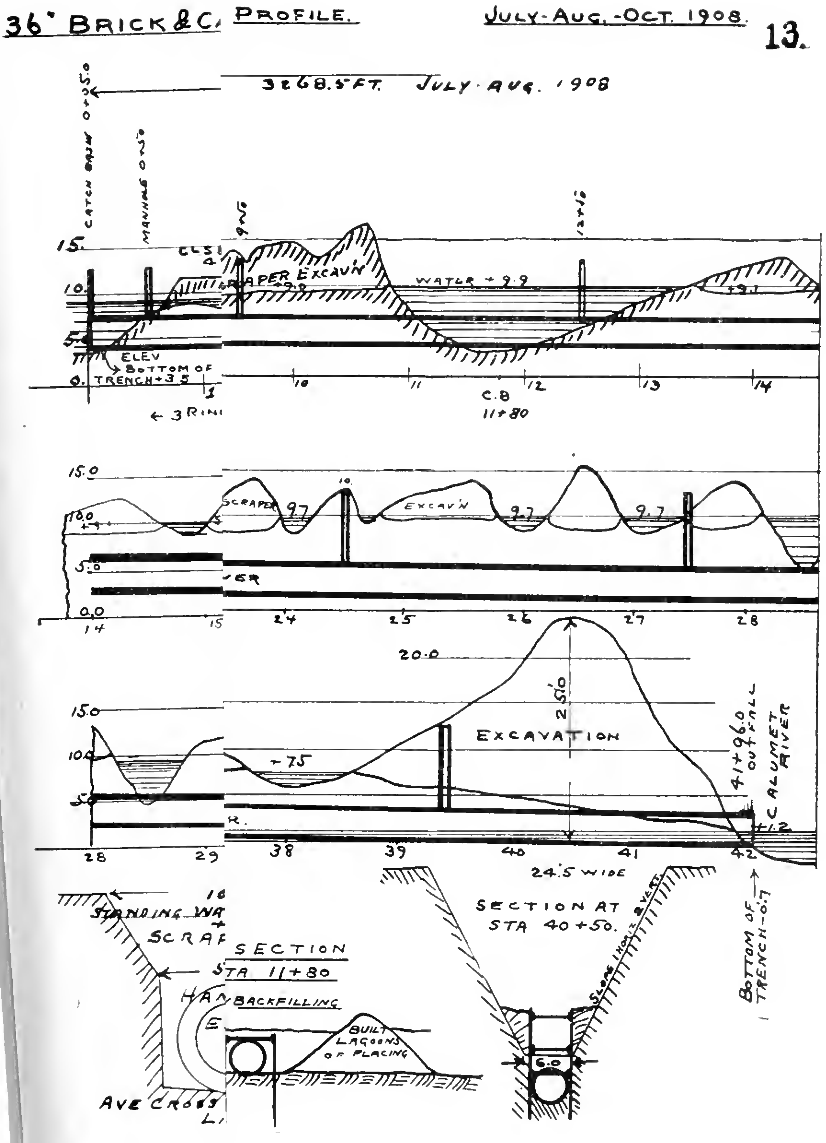
643' OF TRENCH SHEETED, MERELY "STICKING" THE SHEETING
WITH 1 SET OF STRINGERS 36,540' B.M. REQUIRED
490½ HOURS OF LABOR = $134.53
COST PER LIN. FT. TRENCH = 0.764 HOUR $0.21
" " M. FT. B.M. = 13.4 " 3.68
610'. DRIVING IN PLACE OF ABOVE 34,700 FT. B.M.
620 HOURS LABOR $171.20

COST PER FOOT "DRIVING"
1.02 H'RS $0.282
PER M' B.M. 17.9 HRS. $4.95
TOTAL PER FOOT 1.784 HRS. $0.492
" M. FT. B.M. 31.3 " 8.63

THE EXPENSE WAS

124 DAYS TEAMS	$620.00
30 " SLIPHOLDER	60.00
12 " GRUBBER	24.00
TOTAL.	704.00

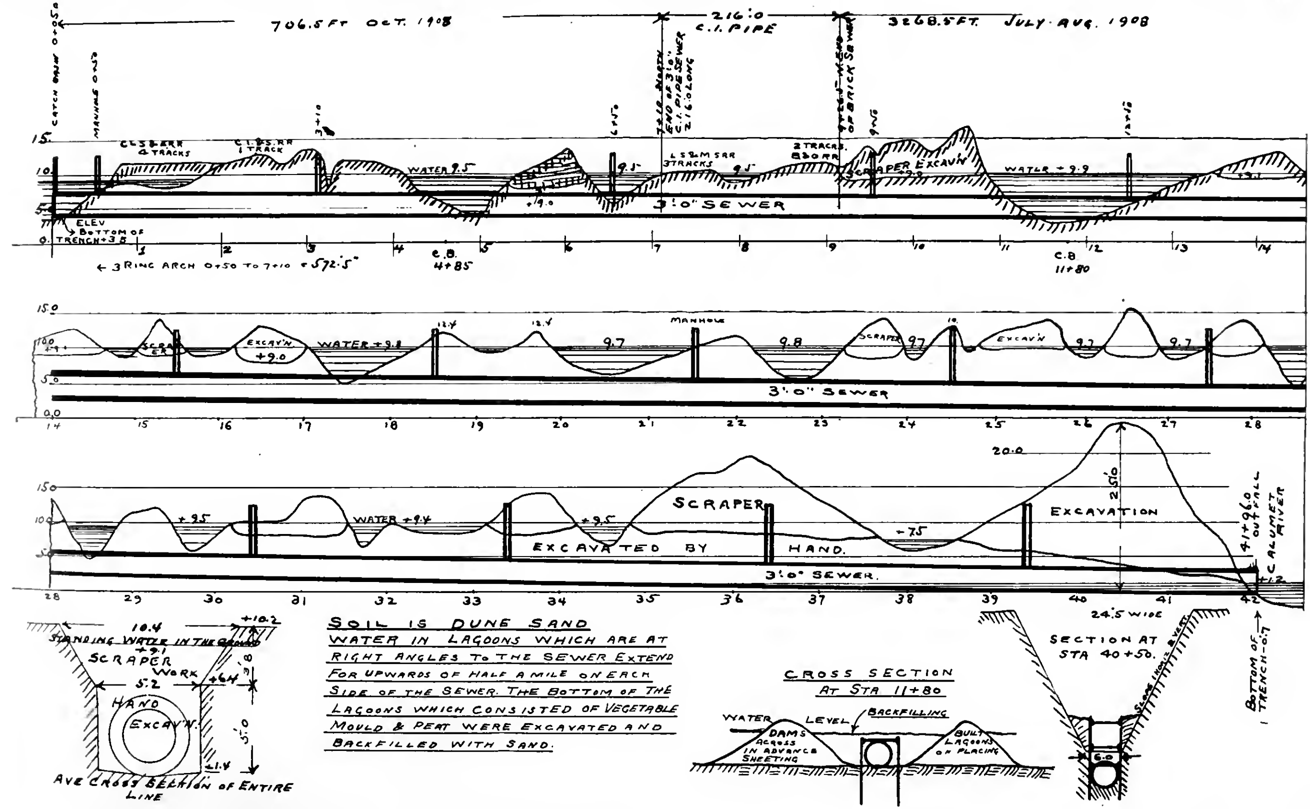
30.1 YDS. PER 10 HR. DAY PER TEAM $0.159 PER CU. YD.


36" BRICK & C
PROFILE.
JULY-AUG.-OCT. 1908.
13.
3268.5 FT. JULY-AUG. 1908
CATCH BASIN 0+3.0
MANHOLE 0+5.0
9+6
12+16
15.
10.
5.
0.
SCRAPER EXCAV'N
WATER +9.9
+9.1
ELEV
BOTTOM OF TRENCH +3.5
10
11
12
13
14
C.B
11+80
← 3 RIN
15.0
10.0
5.0
0.0
SCRAPER
9.7
EXCAV'N
9.7
9.7
14
15
24
25
26
27
28
20.0
15.0
10.0
5.0
+7.5
EXCAVATION
25.0
41+96.0 OUTFALL
CALUMET RIVER
+1.2
28
29
38
39
40
41
42
24.5 WIDE
STANDING WA
SCRAP
SECTION STA 11+80
BACKFILLING
BUILT LAGOONS OF PLACING
AVE CROSS
SECTION AT STA 40+50.
SLOPE 1 HORIZ. 2 VERT.
6.0
BOTTOM OF TRENCH -0.7

K
732

36" BRICK & CAST IRON SEWER C.L.S. & E.R.R. Co
CLARKE TO PINE IND.
NASH-DOWDLE Co.
CONTRACTOR
PROFILE.
JULY-AUG.-OCT. 1908.

13.



SOIL IS DUNE SAND
WATER IN LAGOONS WHICH ARE AT RIGHT ANGLES TO THE SEWER EXTEND FOR UPWARDS OF HALF A MILE ON EACH SIDE OF THE SEWER. THE BOTTOM OF THE LAGOONS WHICH CONSISTED OF VEGETABLE MOULD & PEAT WERE EXCAVATED AND BACKFILLED WITH SAND.

BRICK MAS

14.
1907-'9

LOCATION	DIAM. INTERNAL	BRICKLAYERS		BRICKLAYERS HELPERS, BRICK TOSSERS, SCAFFOLDMEN		MORTAR MIXERS & CARRIERS		SETTING UP & DOWN ARCH FORMS		TOTAL LABOR OF BRICKLAYING	
	INCHES	H'RS	COST	H'RS.	COST	HRS	COST	HRS	COST	HOURS	COST
136 ST. HEGEWISCH	24"	.16	$.28	.4	$.21	.26	$.10	.06	$.004	1.46	.70
10TH AV. GARY IND.	"	.20	.28	.6	.12	.11	.09	.06	.004	1.50	.61
COMM'L AV. HEGEWISCH	"	.22	.25	.63	.20	.34	.11	.01	.006	1.44	.68
C.L.S.&E.RY. KIRK YARD IND	"	.20	.25	.45	.12	.33	.08			1.07	.46
ALLEY 13 GARY	"	.30	.44	.7	.17	.4	.10	.11	.03	2.08	.94
" 3 "	"	.30	.36	.6	.15	.3	.09	.09	03	2.08	.83
" 7 "	"	.30	.40	.4	.17	.3	.10	.10	03	1.70	.90
AVERAGE OR TOTAL	"	.24	.32	.6	.16	.3	.10	.8	.02	1.62	.73
ALLEY 7 GARY	30"	.5	.47	.7	15	.4	.08	.1	.04	2.6	1.00
" 26 "	"	.3	.39	.7	.17	.5	.10	.1	.02	2.4	.97
" 13 "	"	.4	.44	.7	.20	.4	.10	.1	.03	3.0	1.07
AVERAGE	"	.4	.43	.7	.17	.4	.09	.1	.03	2.7	1.01
C.L.S.&E.RY. PINE IND.	36"	3	.41	.9	.28	1.0	.20	.1	.02	2.4	.96
" CLARK-PINE	"	.3	.29	.6	.14	.6	.11	.4	.10	2.8	.91
134 ST. HEGEWISCH	"	.3	.32	1.1	35	.4	.15	.12	.05	2.0	.92
HOWARD AV. "	"	.3	.34	.8	.26	.8	.10	.15	.06	2.4	.97
" "	"	.3	.33	.8	.27	.5	.16	.13	.05	2.0	96
ALLEY 26 GARY	"	.5	.60	1.1	.27	.7	.15	.10	.04	3.3	1.37
C.L.S.&E.RY. KIRK YARD	"	.3	.32	.6	14	.5	.12	.25	.07	1.7	.68
" "	"	.3	.32	.5	18	.5	.14	.4	.13	2.3	1.01
AVERAGE	"	.3	.37	.8	.24	.6	.14	.2	.06	2.4	.97
134 ST. HEGEWISCH	42"	.34	.40	1.1	.33	.5	.18	.13	.05	2.4	1.13
ALLEY 26 GARY	"	.42	.54	.8	.23	.5	.14	.2	.04	2.7	1.25
AVERAGE	"	.38	.47	1.0	.28	.5	.16	.2	.05	2.6	1.19
ALLEY 26 GARY	48	.4	.49	.8	.21	.5	.13	.15	.03	2.9	1.21
134 ST. HEGEWISCH	54	.4	.57	1.0	.35	.6	.23	.2	.07	3.4	1.60
" "	"	.3	.44	1.8	.56	.6	.17	.3	.10	3.4	1.48
ALLEY 2QE. GARY	"	.5	.69	1.1	.30	.7	.17	.2	.05	3.8	1.77
" W. "	"	.7	.87	1.4	.40	.8	.25	.3	.07	4.4	1.87
AVERAGE	"	.5	.65	1.3	.40	.7	.21	.3	.07	3.8	1.68

TOTAL LENGTH 2
TOTAL BRICK 4,4
TOTAL CEMENT
BRICK PER CU. Y
CEMENT " "
VOL. OF 1000 B
CEMENT PER "
AVE BRICKLAID P
MAX. NO. " "
" " " " "
MIN. " " "

ICA NATURAL CEMENTS USED

	CEMENT		OTHER MATERIALS		TOTAL COST PER	
00	CU.YD.	1000 BRICK	CU.YD.	M BRICK	CU YD.	1000 BRICK
$	$	$	$	$	$	$
5.15	0.69	1.31	0.10	0.19	6.82	13.82
4.70	0.45	.87	0.16	.30	6.68	14.10
4.47	0.64	1.28	0.16	29	6.24	12.83
4.96	0.64	1.18	0.13	23	6.91	13.22
4.72	0.45	.88	0.19	.37	6.06	12.47
4.75	0.49	94	0.22	43	6.93	13.72
4.80	0.56	1.08	0.16	30	6.64	13.39

732

BRICK MASONRY LABOR PER LINEAL FOOT OF SEWER

14.
1907-'9

LOCATION	DIAM. INTERNAL	LENGTH	NO. OF RINGS OF BRICK	VOL. OF MASONRY PER LIN. FOOT	NO. OF BRICK PER FOOT - "CAR COUNT" & PER YD.		CEMENT USED IN BARRELS PER			BRICK LAID PER BRICKLAYER PER	LENGTH OF SEWER PER BRICKLAYER	BRICK HAUL		CEMENT HAUL		BRICKLAYERS		BRICKLAYERS HELPERS, BRICK TOSSERS, SCAFFOLDMEN		MORTAR MIXERS & CARRIERS		SETTING UP & DOWN ARCH FORMS		TOTAL LABOR OF BRICKLAYING	
	INCHES	FEET		CU. YD.	LIN. FOOT	CU. YD	LIN. FT.	CU. YD	M. BRICK	8 HR. DAY	PER 8 HR. DAY	HRS	COST	HRS	COST	H'RS	COST	H'RS	COST	HRS	COST	HRS	COST	HOURS	COST
136 ST HEGEWISCH	24"	581	2	.207	114	548	.23	1.12	2.02	4290	37.5	.13	$.086	.05	$0.023	.16	$.28	.4	$.21	.26	$.10	.06	$.004	1.46	.70
10TH AV. GARY IND.	"	936	"	"	104	"	.142	.76	1.48	3800	36.0	.20	.18	.04	.02	.20	.28	.6	.12	.11	.09	.06	.004	1.50	.61
COMM'L AV. HEGEWISCH	"	1336	"	"	116	559	.23	1.19	1.98	4345	37.5	.18	.09	.06	.02	.22	.25	.63	.20	.34	.11	.01	.006	1.44	.68
C.L.S.&E.RY. KIRK YARD IND.	"	4200	"	"	115	548	.14	.67	1.22	4500	41.6	.06	.01	.03	.01	.20	.25	.45	.12	.33	.08			1.07	.46
ALLEY 13 GARY	"	335	"	.24	120	510	.18	.76	1.50	2710	22.7	.50	.18	.03	.02	.30	.44	.7	.17	.4	.10	.11	.03	2.08	.94
" 3 "	"	695	"	"	122	"	.18	.77	1.48	3440	28.0	.5	.18	.04	.02	.30	.36	.6	.15	.3	.09	.09	03	2.08	.83
" 7 "	"	710	"	"	"	"	.18	.77	1.50	3075	25.9	.5	.19	.10	.07	.30	.40	.4	.17	.3	.10	.10	03	1.70	.90
AVERAGE OR TOTAL	"	8793	"	.22	115	527	.17	.77	1.45	4110	35.8	.3	.13	.05	.03	.24	.32	.6	.16	.3	.10	.8	.02	1.62	.73
ALLEY 7 GARY	30"	365	"	.29	149	515	.22	.80	1.49	3120	21.2	.6	.22	.3	.04	.5	.47	.7	15	.4	.08	.1	.04	2.6	1.00
" 26 "	"	855	"	"	"	"	.22	.77	1.50	3800	25.6	.6	.22	.2	.07	.3	.39	.7	.17	.5	.10	.1	.02	2.4	.97
" 13 "	"	367	"	"	148	"	.22	.75	1.48	3360	22.7	.6	.22	.2	.07	.4	.44	.7	.20	.4	.10	.1	.03	3.0	1.07
AVERAGE	"	1587	"	.29	149	515	.22	.77	1.49	3530	23.7	.6	.22	.3	.06	.4	.43	.7	.17	.4	.09	.1	.03	2.7	1.01
C.L.S.&E.RY PINE IND.	36"	705	3 ARCH 2 INVERT	.42	184					4557		.1	.05			3	.41	.9	.28	1.0	.20	.1	.02	2.4	.96
" CLARK-PINE	"	3268.5	2	.324	181	466	.15	.45	.97	4972	330	.6	.24	.3	.03	.3	.29	.6	.14	.6	.11	.4	.10	2.8	.91
134 ST. HEGEWISCH	"	653	"	.29	156	546	.30	1.06	1.96	4950	31.9	.05	.03	.1	.03	.3	.32	1.1	35	.4	.15	.12	.05	2.0	.92
HOWARD AV. "	"	932	"	"	"	"	.31	1.08	1.97	4345	27.9	.24	.12	.1	.04	.3	.34	.8	.26	.8	.10	.15	.06	2.4	.97
" "	"	1700	"	"	"	"	.30	1.06	1.97	4630	29.6	.24	.12	.07	.03	.3	.33	.8	.27	.5	.16	.13	.05	2.0	96
ALLEY 26 GARY	"	1090	"	.33	168	510	25	.75	1.48	2800	16.5	.7	.25	.2	.06	.5	.60	1.1	.27	.7	.15	.10	.04	3.3	1.37
C.L.S.&E.RY KIRK YARD	"	1800	"	.28	158	558	.16	.60	1.04	4870	31.9	.1	.02	.01	.01	.3	.32	.6	14	.5	.12	.25	.07	1.7	.68
" "	"	253	"	"	"	"	.22	.78	1.35	4850	30.7	.6	.21	.1	.03	.3	.32	.5	18	.5	.14	.4	.13	23	1.01
AVERAGE	"	10396.5	"	.31	157	510	.24	.72	1.35	4430	28.3	.32	.13	.13	.03	.3	.37	.8	.24	.6	.14	.2	.06	24	.97
134 ST. HEGEWISCH	42"	1657	"	.36	180	557	.35	1.08	1.95	4250	23.8	.3	.14	.1	.04	.34	.40	1.1	.33	.5	.18	.13	.05	2.4	1.13
ALLEY 26 GARY	"	330	"	.37	186	500	.28	.75	1.50	3450	18.6	.8	.28	.	.02	.42	.54	.8	23	.5	.14	.2	.04	2.7	1.25
AVERAGE	"	1987	"	.36	181	546	.34	1.02	1.87	4130	22.9	.6	.21	.1	.03	.38	.47	1.0	.28	.5	.16	.2	.05	2.6	1.19
ALLEY 26 GARY	48	1325	"	.42	214	512	32	.76	1.49	4370	20.6	.9	.22	.1	03	.4	.49	.8	.21	.5	.13	.15	.03	2.9	1.21
134 ST. HEGEWISCH	54	373	"	.404	224	554	.45	1.10	1.95	4091	18.2	1.1	.34	.1	.04	.4	.57	1.0	.35	.6	.23	.2	.07	3.4	1.60
" "	"	293	"	"	"	"	.46	1.13	2.07	5433	24.9	.3	.17	.1	.04	.3	.44	1.8	.56	.6	.17	.3	.10	3.4	1.48
ALLEY 20 E. GARY	"	1328	"	.46	236	510	.35	.76	1.48	3515	15.0	1.1	.40	.2	.07	.5	.69	1.1	.30	.7	.17	.2	.05	3.8	1.77
" W. "	"	2035	"	"	"	"	.35	.76	1.48	2700	11.5	1.0	.28	.2	.05	.7	.87	1.4	.40	.8	.25	.3	.07	4.4	1.87
AVERAGE	"	4029	-	.43	233	517	.37	.81	1.57	3800	16.4	.9	.30	.2	.05	.5	.65	1.3	.40	.7	.21	.3	.07	3.8	1.68

TOTAL LENGTH 28,117.5 FT. THIS TABLE DOES NOT INCLUDE MANHOLES & CATCH BASINS., PORTLAND & UTICA NATURAL CEMENTS USED.

TOTAL BRICK 4,475,270. TOTAL CU. YDS. 8611.7
TOTAL CEMENT 6561 BBLS.
BRICK PER CU. YD. 520 AVE. OF ALL SIZES.
CEMENT " " " 0.76 BBL. " "
VOL. OF 1000 BRICK (IN MASONRY) 1.93 CU. YDS.
CEMENT PER " " 1.47 BBLS.
AVE BRICK LAID PER BRICKLAYER PER 8 HR DAY 4500.
MAX. NO. " " " " " " " 7583.
" " " " WAS IN A 24" SEWER.
MIN. " " " " " " 54" " " " 2700

SIZE OF SEWER	LABOR COSTS PER CU. YD.		LABOR COSTS PER 1000 BRICK		BRICK CU. YD.	BRICK 1000	CEMENT CU. YD.	CEMENT 1000 BRICK	OTHER MATERIALS CU. YD.	OTHER MATERIALS M BRICK	TOTAL COST PER CU. YD.	TOTAL COST PER 1000 BRICK
	HRS	$	HRS	$	$	$	$	$	$	$	$	$
24"	7.2	3.30	16.2	7.17	2.73	5.15	0.69	1.31	0.10	0.19	6.82	13.82
30"	8.5	3.82	17.3	8.23	2.25	4.70	0.45	.87	0.16	.30	6.68	14.10
36"	7.3	3.18	14.2	6.89	2.26	4.47	0.64	1.28	0.16	29	6.24	12.83
42"	7.6	3.42	14.1	6.85	2.72	4.96	0.64	1.18	0.13	23	6.91	13.22
48"	7.1	3.02	16.0	6.50	2.40	4.72	0.45	.88	0.19	.37	6.06	12.47
54"	9.0	3.96	17.2	7.60	2.46	4.75	0.49	.94	0.22	43	6.93	13.72
AVE	7.8	3.45	16.0	7.21	2.47	4.80	0.56	1.08	0.16	30	6.64	13.39

TOTAL COST OF 15. 1907-10.

Dia.	Location	Length Ft.	Total Labor Hrs	Total Labor $	Materials $	Total Cost $	Days Work Feet	
24"	C.L.S.&E.Ry. Kirk Yd.	4200	5.84	1 64	1.22	2.86	155	2150 Completed Sewer 7583 Brick per Mason } Best 2 Days Work
	Alley 3 Gary	695	6 8	2.27	1 47	3.64	120	Average (of 2 days) per day
	" 13 "							
	Comm'l Av. Hegewisch	1336	5.8	1.86	1.35	3.21	148	Well Points Used
	136 St .	581	6.5	2.15	1.46	3.61	145	" " "
	10th Av. Gary	936	9.7	3.04	1.00	4.04	142	" " " in part
	Alley 13 "	335	3.3	3.88	1.86	5.74	91	
	" 7 "	710	13.3	3.80	1.80	5.60	100	The rate of progress
								is for 4 bricklayers
30	" 26 "	855	10.4	3.29	2.05	5.25	71	working 8 hours and
	" 7 "	365	14.8	4.54	2.00	6.54	86	the necessary force
	" 13 "	367	16.3	4.77	2.00	6.77	92	of trenchmen at
								9 Hours per day.
36	C.L.S.&E.Ry. Kirk Yd.	253	7.5	2.81	1.66	4.47		
	" Pine	216						C I Pipe instead of Brick
	" "	70	8.9	2.72				3 Rings on Arch
	" Kirk Yd.	1800	8.4	2.32			113	
	Alley 26 Gary	1090.	14.8	4.48	2.16	6.64	67	
	C.L.S.&E.Ry. Clark	3268.	8.9	3.03			132	
	134 St Hegewisch	653	11.5	3.75	2.00	5.75	127	
	Howard Av	932	7.3	2.51	1 88	4.39	116	Well Point Pumping
	" . .	1700	9.1	3.46	2 26	5.72	133	
42	134th St. "	165	11.3	3.91	2 86	6.7 7	122	
	Alley 26 Gary	33	10.8	3.57	2.03	5.60	74	
48	" " "	132	14.1	4.33	2.63	6 96	82	
	Bl. Fces. Ind. Steel Co	89						
54	134th St. Hegewisch	37	26.6	7.63	3.99	11.62	62	Under G R R tracks
	"	29	11.4	4.39	3.20	7.59	81	
	Alley 20 E. Gary	132	24.7	7.40	3.01	10.41	62	Very wet trench
	" " W "	203	20.0	6.00	3.15	9.15	70	

TOTAL COST OF BRICK SEWERS.

15.
1907-10.

DIA.	LOCATION	LENGTH FT.	DEPTH FT.	EXCAVATION		SHEET'G & BR'C'G		BACKFILL		PUMPING		TOTAL TRENCHING		BRICKLAYING LABOR		GEN'L LABOR		TOTAL LABOR		MATERIALS	TOTAL COST	DAYS WORK	
				HOURS	COST	HRS.	$	HRS	$	HRS.	$	HRS	$	HRS	$	HRS.	$	H'RS	$	$	$	FEET	
24"	C. L. S. & E. RY. KIRK YD.	4200	6.4	2.7	$ .60	1.3	.30	IN EXCAV'N		.1	.05	4.1	.95	1.3	.50	.44	.19	5.84	1.64	1.22	2.86	155	2150 COMPLETED SEWER 7583 BRICK PER MASON } BEST 2 DAYS WORK
	ALLEY 3 GARY	695	7.8	3.0	.78	1.3	39	.3	.08	.1	.02	4.7	1.27	19	.88	.2	12	6.8	2.27	1.47	3.64	120	AVERAGE (OF 2 DAYS) PER DAY
	" 13 "		8.0																				
	COMM'L AV. HEGEWISCH	1336	9.7	1.9	.52	.7	.19	.5	.11	1.0	.28	4.1	1.10	1.4	.68	.3	.09	5.8	1.86	1.35	3.21	148	WELL POINTS USED
	136 ST "	581	10.0	2.4	.65	1.0	.28	.4	.12	1.1	.30	4.9	1.35	1.5	.70	.3	.10	6.5	2.15	1.46	3.61	145	" " "
	10TH AV GARY	936	11.7	3.3	.77	1.6	.47	.3	.14	1.6	.47	6.8	1.85	1.5	.61	1.4	.58	9.7	3.04	1.00	4.04	142	" " " IN PART
	ALLEY 13 "	335	12.3	6.4	1.46	3.1	.89	.7	14	.4	.10	10.6	2.59	2.3	1.04	.4	.25	13.3	3.88	1.86	5.74	91	
	" 7 "	710	14.7	7.3	1.66	2.4	.69	.9	.21	.4	.10	11.0	2.65	2.0	.96	.3	19	13.3	3.80	1.80	5.60	100	THE RATE OF PROGRESS
																							IS FOR 4 BRICKLAYERS
30	" 26 "	855	11.3	34	1.08	2.0	.50	1.4	.30	6	.18	7.4	1.97	2.6	1.04	.4	19	10.4	3.29	2.05	5.25	71	WORKING 8 HOURS AND
	" 7 "	365	14.5	7.4	2.08	2.7	.75	1.3	.22	.2	.11	11.6	3.15	2.8	1.18	.4	.21	14.8	4.54	2.00	6.54	86	THE NECESSARY FORCE
	13 "	367	15.1	9.1	2.25	3.2	.87	1.6	.14	.4	.10	13.3	3.36	2.5	1.14	.5	.27	16.3	4.77	2.00	6.77	92	OF TRENCHMEN AT
																							9 HOURS PER DAY.
36	C. L. S. & E. RY. KIRK YD.	253	3.6	1.6	.42	1.6	.49	.3	.08	.6	.22	4.1	1.21	2.6	1.04	9	51	7.5	2.81	1.66	4.47		
	" PINE	216	6.0			CAST IRON PIPE INSTEAD																	C I PIPE INSTEAD OF BRICK
	" "	705	8.0	3.7	.81	1.4	.46	.02	.04	.9	.19	6.0	1.50	2.4	.97	.5	.25	8.9	2.72				3 RINGS ON ARCH
	" KIRK YD.	1800	7.1	3.8	.81	2.0	.45			4	.18	6.1	1.44	1.8	.71	.5	17	8.4	2.32			113	
	ALLEY 26 GARY	1090.	7.3	5.3	1.31	4.0	1.08	1.3	.30	3	.10	10.9	2.79	3.4	1.47	.5	22	14.8	4.48	2.16	6.64	67	
	C. L. S. & E. RY. CLARK	32685	9.0	3.7	1.05	1.7	44	.3	.06	.4	.14	6.1	1.69	2.0	.93	.8	.41	8.9	3.03			132	
	134 ST HEGEWISCH	653	9.5	3.8	118	29	.86	8	20	.4	14	7.9	2.38	2.0	.92	1.4	.45	11.5	3.75	2.00	5.75	127	
	HOWARD AV	932	11.0	3.0	88	.6	19	.4	15	8	.22	4.8	1.43	2.4	97	.1	.11	7.3	2.51	188	4.39	116	WELL POINT PUMPING
	" " "	1700	11.4	3.3	1.28	2.3	.83	.5	12	.5	10	6.6	2.32	2.0	.96	.5	.18	9.1	3.46	2.26	5.72	133	
42	134TH ST. "	1657	12.0	5.2	1.68	2.1	.64	.5	14	.5	.12	8.3	2.57	2.4	1.13	.6	.21	11.3	3.91	2.86	6.77	122	
	ALLEY 26 GARY	330	17.2	3.0	.74	2.4	.68	1.7	.52	.3	.16	7.4	2.04	3.0	1.33	.4	.20	10.8	3.57	2.03	5.60	74	
48	" " "	1325	14.0	5.9	1.53	3.4	.85	.4	16	.6	.18	10.3	2.72	3.1	1.29	.7	.32	14.1	4.33	2.63	6.96	82	
	BL. FCES IND. STEEL CO.	894	14.6	3.0	.89	.2	.09	.6	15	NONE		3.8	1.13	CONCRETE									
54	134TH ST HEGEWISCH	373	12.0	13.0	3.18	4.9	1.35	1.1	.26	2.5	.68	21.5	5.47	3.4	1.60	1.4	.56	26.6	7.63	3.99	11.62	62	UNDER G R R TRACKS
	"	293	12.7	2.9	1.19	2.3	.76	.3	11	.5	.17	6.0	2.23	3.4	1.48	2.0	.68	11.4	4.39	3.20	7.59	81	
	ALLEY 20 E. GARY	1328	19.4	13.4	3.24	3.4	1.07	.9	27	1.0	.27	18.7	4.87	4.1	1.78	1.9	.75	24.7	7.40	3.01	10.41	62	VERY WET TRENCH
	" " W "	2035	21.9	9.0	2.00	3.6	.93	1.0	.27	1.4	.39	14.4	3.59	4.8	2.02	.8	.39	20.0	6.00	3.15	9.15	70	

19.

JULY-DEC. 1907.

6' 0" CIRCUL WDLE CO.
CONTRACTOR

CHARACTER OF W	N AND TRACK.	PER LINEAL FOOT OF SEWER	UNDER 2ND R.R. TRACK — COSTS — HOURS	COST	PER LIN. FT. OF SEWER	BEYOND R.R. TRACKS - FREE FROM OBSTRUCTIONS. — COSTS — HOURS	COST	PER LIN. FOOT OF SEWER
		$		$	$		$	$
EXCAVATION BY MA	50		98	33.80		1570	547.80	
DISMANTLING, LOADING, UN	60		177	48.25		2444	809.80	
OPERATION	70		19	6.65		310	108.00	
DISMANTLING & LOADI	80	3.44	294	88.70	2.07	4324	1465.60	.80
EXCAVATION BY I								
SHEETING & BRACIN	55		80	32.85				
SHEETING REMOVE	FT	IN	7	2.90				
STEAM PUMPING	20		40	13.00				
EXCAVATION	60		31	8.35				
	35	5.16	158	57.10	1.33	8961	2[illegible]45.45	1.34
BACKFILLING BY	15		41	13.10				
MACHINE				—		355	99.35	
HAND & SCRAPE								
	75	.40	41	13.10	.30	1429½	433.15	.24
	90	9.00	493	158.90	3.70	14,714½	4344.20	2.38
CONCRETE TR								
STONE & SAND } FROM								
CEMENT								
MIXER MEN								
WHEELING CONCR								
SPREADING & TAM								
FORMS								
RUNWAYS								
STEAM PUMPIN	50		89	25.75				
BACKFILLING								
MASONRY	60	3.04	376	118.65	2.75	9213	2377.90	1.30
GENERAL EXPEN								
CLEANING UP			24	6.85	.16	94	45.45	
WATCHMEN	15		74	15.40	.40	569	128.05	
SUPERINTENDEN	20		48½	37.75		691½	527.50	
GENERAL EXPE	35	2.54	146½	60.00	1.40	1354½	700.65	.39
TOTAL LAB	35	14.58	1015½	337.55	7.85	25282	7422.75	4.07
			43.0 FT.			1823.0 FT.		
	YD. $	0.843	550 YDS PER CU. YD.		$0.291	16400 CU. YDS. PER CU YD $		0.265
	. $	3.67	36 " CONCRETE . $		3.30	1494 " " CONC. " " $		1.59
	.74		CEM. 40¼ BBLS $54.34			1148 BBLS $1549.80		
	BLS	$2.40	PER CU YD	1.12 BBLS.	$1.51	PER CU. YD.	0.77 BBLS.	$1.04
	"	$1.89	" LIN FT	0.94 "	$1.27	" LIN. FT.	0.63 "	$0.85

19.

6'-0" CIRCULAR CONCRETE "MILL" SEWER - INDIANA STEEL CO. GARY IND. NASH-DOWDLE CO. CONTRACTOR JULY-DEC., 1907.

Character of Work	Total Length of Sewer							River Extension and Under 1st R.R. Track.			Under 2nd R.R. Track			Beyond R.R. Tracks-Free from Obstructions.		
	%	Costs		Work Done	Cost Per			Costs		Per Lineal Foot of Sewer	Costs		Per Lin. Ft. of Sewer	Costs		Per Lin. Foot of Sewer
		Hours	Cost		Hour	Unit of Work	Lin. Foot Sewer	Hours	Cost		Hours	Cost		Hours	Cost	
Excavation by Machine			$	1910'-0" Trench	$	$	$		$	$		$	$		$	$
Dismantling, Loading, Unloading, Reerecting		1940	676.10					272	94.50		98	33.80		1570	547.80	
Operation		2993½	1003.65	16050 Cu. Yds.				372½	145.60		177	48.25		2444	809.80	
Dismantling & Loading onto Cars		383	133.35					54	18.70		19	6.65		310	108.00	
Total.		5316½	1813.10	16050 Cu. Yds.	.342	0.113	.93	698½	258.80	3.44	294	88.70	2.07	4324	1465.60	.80
Excavation by Hand																
Sheeting & Bracing Placed		3846	1220.50	111780' BM				597½	173.55		80	32.85				
Sheeting Removed		1219½	278.30	102460' "		2.71		Sheeting Left In			7	2.90				
Steam Pumping		428	109.85	1700 Cu. Yds.				120	30.20		40	13.00				
Excavation		4957½	1281.25	1700 Cu. Yds.				614½	183.60		31	8.35				
Total		10451	2889.90	17750 Cu. Yds.	.277	0.163	1.49	1332	387.35	5.16	158	57.10	1.33	8961	2445.45	1.34
Backfilling by																
Machine		1205½	375.65	14900 Cu. Yds.				90	28.75		41	13.10				
Hand & Scrapers		355	99.35	350 "				—	—			—		355	99.35	
Total		1560½	475.06	15250 "	.305	0.31	.25	90	28.75	.40	41	13.10	.30	1429½	433.15	.24
Trenching Total		17328	5178.00	17750 "	.30	0.292	2.67	2120½	674.90	9.00	493	158.90	3.70	14,714½	4344.20	2.38
Concrete																
Stone & Sand } from Cars into Concrete Mixer		3162½	810.15	1592	2.0	.51										
Cement		436½	96.45	Cu. Yds. of	.3	.06										
Mixer Men		1655	481.75	Concrete in	1.0	.30										
Wheeling Concrete		1660	401.90	1907'-0" Sewer &	1.0	.25										
Spreading & Tamping,		1075½	296.55	9 Manholes	.7	.19										
Forms		1000	286.65	Equal to 34'.0 of	.6	.18										
Runways		535½	126.45	Sewer Total	.3	.08										
Steam Pumping		429	109.75	Equivalent Sewer	.3	.07		20	6.50		89	25.75				
Backfilling		433	114.50	1941'-0"	.3	.07										
Masonry Total		10387	2724.15	1941'-0"	6.5	1.71	1.40	798	227.60	3.04	376	118.65	2.75	9213	2377.90	1.30
General Expense																
Cleaning Up		118	52.30								24	6.85	.16	94	45.45	
Watchmen		716	160.60					73	17.15		74	15.40	.40	569	128.05	
Superintendence		932	738.10					192	173.20		48½	37.75		691½	527.50	
General Expense Total		1766	951.00	"	.54	.60	.49	265	190.35	2.54	146½	60.00	1.40	1354½	700.65	.39
Total Labor		29481	8853.15	"	0.30	5.57	4.56	3183½	1092.85	14.58	1015½	337.55	7.85	25282	7422.75	4.07
Length	1941.0 Ft.							75.0 Ft.			43.0 Ft.			1823.0 Ft.		

			Excav'n 800 Cu. Yds. Per Cu. Yd.		$0.843	550 Cu. Yds. Per Cu. Yd.		$0.291	16400 Cu. Yds. per Cu. Yd. $		0.265
			Concrete 62 " " Per Cu. Yd.		$3.67	36 " Concrete		$3.30	1494 " " Conc. " " $		1.59
Cement 1292½ Bbls $1744.88			Cement 104¼ Bbls $140.74			Cem. 40¼ Bbls $54.34			1148 Bbls $1549.80		
" Per Cu. Yd. of Concrete	0.81 Bbl.	$1.094	" Per Cu. Yd.	1.78 bbls	$2.40	Per Cu. Yd.	1.12 Bbls.	$1.51	Per Cu. Yd.	0.77 Bbls.	$1.04
" " Lin. Ft. of Sewer	0.67 Bbl.	$0.905	" " Lin. Ft.	1.4 "	$1.89	" Lin. Ft.	0.94 "	$1.27	" Lin. Ft.	0.63 "	$0.85

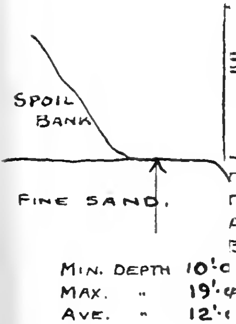
20.

6'-0" CIRCU LE Co.
RACTOR

JULY-DEC. 1907.

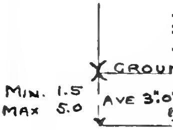
SHEET PILING & BRACING

SHEETING - 2"×8"-12'-0" HEMLOCK: HAND PLACED AND MAULED FOR A "TOE HOLD" OF 2'-0"
62,000 FT. B.M. LUMBER DELIVERED & USED FOR SHEETING & BRACING, 55000 FT. B.M. RECOVERED 7000 FT. B.M. USED UP IN THE FIRST 115'-0" WHERE BACKFILLING WAS REQUIRED TO BE DONE AT ONCE.
STRINGERS WERE 3"×12" - 16'-0"
BRACES " 6"×6" - 5'-4" ℄ TO ℄ USING 2 SETS OR TIERS. A SCREW BRACE & "SHOES" USED AT JOINTS OF STRINGERS.



BACKFILLING BY HAND & SCRAPERS WAS DONE TO RESTORE TO USE A THIRD R.R. TRACK WITHOUT DELAYING THE DIGGING.

THE FIRST 72½ FEET WAS UNDER A R.R. TRACK, IN SAND, SLAG LUMPS AND EXTENDED INTO THE CALUMET RIVER, WHOSE BOTTOM WAS A SOFT OOZE WHICH WAS REMOVED & BACKFILLED WITH SAND.
THE 2ND 43'-0" WAS IN SLAG, & SAND & UNDER A R.R. TRACK.
MANHOLES WERE TAKEN AS BEING EQUAL TO 3.774 FT. OF SEWER. THEREFORE 9 = 34'-0"



CEMENT, STONE, LIMESTONE SCREENINGS, & SAND WERE DELIVERED IN CARS ON TRACKS FROM 20'-0" TO 150'-0 FROM THE MIXER. OCCASIONALLY CARS WERE UNLOADED INTO STOCK PILES. STONE & SAND CARS WERE "SIDE DUMP" GONDOLAS.

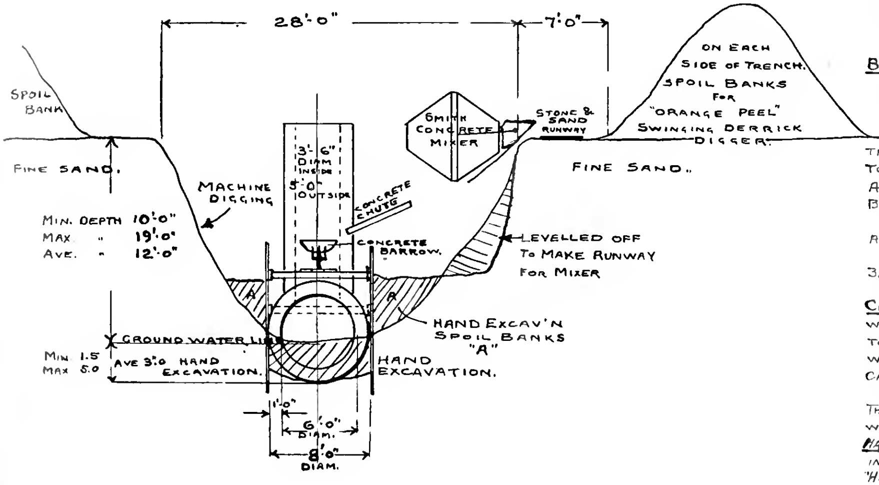
THE "STEAM PUMPING" WAS FOR SUPPLYING THE MACHINES WITH WATER & PUMPING OUT THE SEWER.
HAND "BAILING" OF WATER WAS CHARGED DIRE INTO "SPREADING & TAMPING" CONCRETE OR T. HAND EXCAVATION" AS THE WORK REQUIRED IT.

CEMENT = 0.812 BBL = $1.42 PER CU. YD. OF CONCRETE
= 0.67 " = $1.17 " LIN. FT. OF SEWER.
BACKFILLING BY MACHINE TOOK 22½ DAYS. EQUAL TO 91.0 = PER DAY OR $0.175 PER LIN. FOOT.

CONCRETE PLACED IN 41 DAYS = 38.83 CU. YDS OR 47.3 LIN. FT. OF SEWER PER DAY.
0.825 CU. YD. PER LIN. FT.

6'-0" CIRCULAR CONCRETE "MILL" SEWER INDIANA STEEL CO GARY IND. NASH-DOWDLE CO. CONTRACTOR

20.
JULY-DEC. 1907.



SHEET PILING & BRACING

SHEETING - 2"x8"-12'-0" HEMLOCK: HAND PLACED AND MAULED FOR A "TOE HOLD" OF 2'-0"
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STRINGERS WERE 3"x12"-16'-0"
BRACES " 6"x6" - 5'-4" ⊄ TO ⊄ USING 2 SETS OR TIERS. A SCREW BRACE & "SHOES" USED AT JOINTS OF STRINGERS.

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TOTAL COST OF 12 — 1907-09.

12" SEWERS. AT.	LENGTH	DEP OR $	MATERIALS. $	TOTAL COST. $	DAILY WORK LIN. FT.	
BUFFALO AV. HEGEWISCH	668	6.362	.587	.95	334	WELL POINT PUMPING
CARONDELET AV. "	1332	6.653	.584	1.24	164	" " "
ERIE N. " "	1340	6.442	.562	1.00	335	" " "
C.L.S. & E. RY KIRK YD.	1200	7.49	.31	.80		DRY TRENCH
HOUSTON AV HEG'W'H	1337	.523	.543	1.065	268	WELL POINT PUMPING
ONTARIO - N. "	668	.68	.55	1.23	300	" " "
ALLEY 8 GARY	425	8.44	.37	1.81		MUCK BOTTOM 2'6" DEEP REPLACED WITH SAND
" 9 "	"	9.58	.36	.94		DRY TRENCH
SUPERIOR AV. N. HEG.	670	.612	.617	1.23	297	"POINT" PUMPING
" " S. "	1298	.685	.545	1.23	162	" "
HOUSTON " - "	25	10.33	1.092	2.424		TRENCH PUMP'G
ONTARIO " "	1173	.73	.58	1.31	195	POINT PUMPING
HOUSTON " " "	455	785	.632	1.42	310	" "
BUFFALO " " "	1163	11.91	.54	1.45	256	" "
ERIE " " "	831	1 86	.57	1.44	208	" "
ALLEY 10 GARY	425	1.56	.36	.92		DRY TRENCH
15" PIPE SEWERS.						
BUFFALO AV. HEG.	668	8.89	.69	1.58	223.	WELL POINT PUMPING
HOUSTON " "	669	8.59	.71	1.30	335.	" " "
ONTARIO " "	664	9.80	.69	1.49	192.	" " "
CARONDELET AV. "	672	9.79	.72	1.51	223.	" " "
SUPERIOR AV. "	660	9.77	.71	1.48	223.	" " "
ERIE " "	669	10.77	.70	1.47	192.	" " "
18" PIPE SEWERS						
C.L.S. & E.R.R. KIRK YD.	825.	6.553	.518	1.07		DRY TRENCH
" "	1422	8.31	1.03	2.34		TRENCH PUMPING
HOUSTON AV. HEGEWISCH	661	9.76	.85	1.61	168	WELL POINT "
" "	22	14.30	.49	1.79		TRENCH "
CARONDELET AV. "	423	14.30	.96	2.25	106	WELL POINT "
" "	165	2.16	.48	2.64	165	TRENCH "
ONTARIO " "	664	1.12	.92	2.04	192	WELL POINT "
ERIE " "	661	11.85	.93	1.78	268	" " "
20" PIPE SEWER						
ALLEY 8 GARY	1112.5	13.21	1.06	4.27	101	MUCK BOTTOM - TIMBER CRADLE BUILT
24" PIPE SEWER						
C.L.S. & E.RY GARY	510.	12.29	1.01	2.30		DRY TRENCH

TOTAL COST OF 12"-15"-18" PIPE SEWERS.

1907-09.

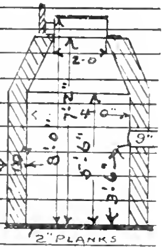
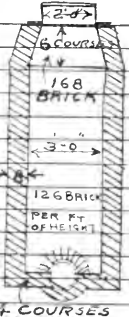
12" SEWERS. AT.	LENGTH	DEPTH	EXCAV'N.		SH'TG. & BR'G		BACKFILL		PUMPING		TOTAL TRENCHING		PIPE LAYING		GENERAL LABOR		TOTAL LABOR		MATERIALS. $	TOTAL COST. $	DAILY WORK LIN.FT.	
			HRS	$	HRS.	$	HRS	$	HRS.	$	HRS.	$	HRS.	$	HRS.	$	HRS	$				
BUFFALO AV. HEGEWISCH	668	6.5	0.5	.15	-	-	.2	.034	.5	.12	1.2	.304	.1	.039	.1	.029	1.4	.362	.587	.95	334	WELL POINT PUMPING
CARONDELET AV. "	1332	6.7	1.1	.32	.1	.03	.29	.073	.43	.117	1.93	.54	.18	.053	.16	.06	2.27	.653	.584	1.24	164	" " "
ERIE N. " "	1340	6.9	.5	.14	.2	.053	.3	.073	.4	.107	1.4	.376	.1	.034	.1	.032	1.6	.442	.562	1.00	335	" " "
C.L.S. & E. RY KIRK YD.	1200	7.5	.9	.23	.5	.13	.1	.04	0	.0	1.5	.32	.2	.08	.2	.09	1.9	.49	.31	.80		DRY TRENCH
HOUSTON AV HEG'W'H	1337	"	.8	.24	.17	.053	.19	.065	.34	.09	1.5	.447	.15	.036	.11	.04	1.76	.523	.542	1.065	268	WELL POINT PUMPING
ONTARIO - N. "	668	-	.8	.20	.2	.07	.3	.08	.6	.18	1.9	.53	.15	.09	.29	.06	2.34	.68	.55	1.23	300	" " "
ALLEY 8 GARY	425	8.0	1.64	.37	1.0	.27	1.2	.44	.1	.03	3.94	1.11	.4	.13	.5	.23	5.7	1.44	.37	1.81		MUCK BOTTOM 2'6" DEEP REPLACED WITH SAND
" 9 "	"	9.4	1.2	.31	.2	.065	.1	.05	NO	NE	1.5	.43	.4	.11	.1	.045	2.0	.58	.36	.94		DRY TRENCH
SUPERIOR AV. N. HEG.	670	9.5	.8	.21	.1	.035	.1	.025	.9	.23	1.9	.50	.23	.06	.1	.05	2.23	.612	.617	1.23	297	"POINT" PUMPING
" " S. "	1298	9.8	.94	.24	.26	.078	.3	.065	.6	.166	2.1	.55	.2	.06	.2	.07	2.5	685	.545	1.23	162	" "
HOUSTON " " "	25	10.0	2.4	.53	1.8	.33	.2	.04	IN EX	CAV'N	4.4	.90	.2	.05	1.1	.38	5.5	1.33	1.092	2.424		TRENCH PUMP'G
ONTARIO " "	1173	"	1.1	.30	.2	.069	.4	.089	.7	.188	2.4	.646	.2	.055	.1	.03	2.7	.73	.58	1.31	195	POINT PUMPING
HOUSTON " " "	455	"	1.1	.37	.2	.071	.25	.06	.8	.18	2.2	.648	.15	.028	.13	.073	2.5	785	.632	1.42	310	" "
BUFFALO " " "	1163	10.5	1.4	.35	.4	.123	.4	.074	.9	.22	3.1	.772	.17	.07	.18	.066	3.5	.91	.54	1.45	256	" "
ERIE " " "	831	11.0	1.5	.25	.3	.07	.6	.14	.8	.20	3.2	.76	.2	.07	.10	.03	3.5	.86	.57	1.44	208	" "
ALLEY 10 GARY	425	11.4	1.0	.31	.3	.08	.2	.06	NO	NE	1.5	.45	.4	.06	.1	.05	2.0	.56	.36	.92		DRY TRENCH
15" PIPE SEWERS.																						
BUFFALO AV. HEG.	668	8.2	1.3	.30	.4	.11	.4	.09	1.0	.27	3.1	.77	.14	.04	.16	.08	3.54	.89	.69	1.58	223.	WELL POINT PUMPING
HOUSTON " "	669	8.3	.6	.20	.3	09	.2	.07	.6	.16	1.73	.517	.12	.038	.09	.03	1.94	.59	.71	1.30	335.	" " "
ONTARIO " "	664	9.0	1.25	.33	.16	.05	.85	.14	.6	.17	2.9	.70	.24	.07	.1	.03	3.0	.80	.69	1.49	192.	" " "
CARONDELET AV "	672	9.2	1.26	.34	.3	.09	.25	08	.5	.14	2.3	.64	.17	.054	.24	.09	2.7	.79	.72	1.51	223.	" " "
SUPERIOR AV "	660	9.5	1.5	.34	.3	.07	.2	.04	.7	.19	2.7	.63	.2	.078	.1	.06	3.0	.77	.71	1.48	223.	" " "
ERIE "	669	10.0	1.5	.41	.2	.06	.2	.03	.6	.14	2.5	.64	.2	.08	.1	.05	2.8	.77	.70	1.47	192.	" " "
18" PIPE SEWERS																						
C.L.S. & E.R.R. KIRK YD.	825.	68	1.0	26	.4	.075	.1	.035	NONE		1.5	.37	.24	.12	.1	.06	1.84	.553	.518	1.07		DRY TRENCH
" "	1422	8.5	1.5	.61	1.0	.33	.1	.04	.1	.03	2.4	1.01	.3	.41	.4	.19	3.12	1.31	1.03	2.34		TRENCH PUMPING
HOUSTON AV HEGEWISCH	661	9.5	1.2	.37	.3	.10	.2	.07	.5	.15	2.3	.69	.1	.04	.1	.03	2.5	.76	.85	1.61	168	WELL POINT "
" "	22	10.0	.9	.21	1.5	.45	.1	.08	.2	.04	2.5	.78	.2	.07	.7	.45	3.4	1.30	.49	1.79		TRENCH "
CARONDELET AV. "	423	10.5	1.3	.45	.6	.19	.2	.08	1.1	.33	3.25	1.05	.3	.14	.2	.11	3.9	1.30	.96	2.25	106	WELL POINT "
" "	165	"	4.0	1.11	2.0	.62	.2	.07	.1	.03	6.3	1.83	.3	.16	.4	.18	7.1	2.16	.48	2.64	165	TRENCH "
ONTARIO " "	664	"	1.9	.49	3	.08	.7	.17	.9	.23	3.8	.98	.25	.09	.16	.05	4.2	1.12	.92	2.04	192	WELL POINT "
ERIE "	661	11.0	1.4	.40	.3	.10	.2	.05	.7	.18	2.7	.74	.16	.06	.13	.05	3.0	.85	.93	1.78	268	" " "
20" PIPE SEWER																						
ALLEY 8 GARY	1112.5	15.0	6.5	1.32	31	.74	.7	28	.6	.20	11.0	2.58	1.0	.22	1.0	.40	12.7	3.21	1.06	4.27	101	MUCK BOTTOM - TIMBER CRADLE BUILT
24" PIPE SEWER																						
C.L.S. & E. RY GARY	510.	12.0	1.8	.61	5	20	.2	.09	NONE		2.5	.90	.7	.20	.4	.19	3.6	1.29	1.01	2.30		DRY TRENCH.

MANHOLES, CATC

HEGI

24.

AUG-DEC 1909.

LOCATION	SIZE OF SEWER	NO. BUILT	IN CONNECTIONS			COST PER FT. OF MAIN SEWER				REMARKS.
			MATL'S	TOTAL	COST PER FOOT.	MAN HOLES	CATCH BASINS	C. B. CONN'TNS	TOTAL	
134TH ST W.	4' 6"	2		$7.48	$047	$.099	$097	$.026	$ 222	LABOR INCLUDES TEAMING OF M'TLS.
" " E	"	1		7.53	47	043	.304	081	438	
AVE	"	3		7.50	.47	068	212	055	.335	
" "	3'-6	10		7.53	47	089	.342	091	.512	
HOWARD AVE.	3-0	10		6 85	43	08	.23	056	.366	
"	"	6		7 48	47	089	.19	049	.327	
134TH ST	"	4		6 48	.40	.12	.443	.10	.663	
AVE.	"	20		6.86	43	088	252	.06	.40	
136TH ST.	2-0	3		9.78	.61	.07	.31	.10	.48	
COMMERCIAL AV.	"	10		6.24	.39	.11	.264	.056	.43	
AVE.	"	13		7.41	.46	.10	.28	07	.45	
ERIE AV.	18"	4		8.19	.51	.15	.156	.05	.356	
ONTARIO AV.	"	5		7 98	.50	.205	.192	.048	.445	
CARONDELET AV.	"	5		5.68	.36	248	.172	034	.454	CATCH BASIN
HOUSTON AV.	"	5		6.39	.40	.158	.164	037	.359	
AVERAGE	"	19		7.06	.44	.19	.172	043	.405	
ERIE AV.	15"	6		8.19	.51	.25	.234	.073	.557	 2'-0" 6 COURSES 168 BRICK 3-0 8 126 BRICK PER FT OF HEIGHT 4 COURSES
SUPERIOR AV	"	5		5.78	.36	.213	.158	.035	.406	
CARONDELET AV.	"	5		5.68	.36	.215	250	.053	.518	
ONTARIO AV	"	5		7.98	.50	.175	.265	.072	.512	
HOUSTON AV	"	4		6.18	.38	.149	.247	057	.456	
BUFFALO AV	"	5		6.08	.38	144	.153	.037	.384	
AVERAGE	"	30		6.73	.42	.198	220	.054	472	
ERIE AV S	12"	6		7.89	.50	212	.16	048	.420	
BUFFALO AV.	"	9		6.08	.38	.207	.175	.043	.425	
SUPERIOR AV "	"	10		5.68	.36	.212	.16	.035	.407	
ONTARIO AV "	"	9		7.98	.50	.19	198	055	.443	
HOUSTON AV	"	3		6.13	.38	.15	.12	.026	296	
SUPERIOR AV N.	"	5		5.68	.36	.18	.31	.067	557	
ONTARIO AV	"	5		6.18	.38	.154	.35	.075	579	201 BRICK
HOUSTON AV. "	"	11		5.68	.35	.165	.25	.051	.466	MANHOLE FOR
CARONDELET AV "	"	10		8.19	.51	.196	.25	074	520	PIPE SEWER.
ERIE AV "	"	10		6.18	.38	.164	.235	.061	.460	
BUFFALO AV "	"	5		6 08	.38	.136	.31	.072	508	HEIGHT OF MAN
AVERAGE	"	83		6.60	.41	.183	.226	055	.464	HOLES GIVEN ARE
AVERAGE OF BRICK SEWERS		46		7.23	0.46	.102	.236	.079	.417	TOP OF SEWER TO
" " PIPE	"	13		6.74	0.42	.188	.215	.052	.455	TOP OF BRICK
GENERAL AVERAGE		17	a.58	6.81	0.43	.164	.22	06	0.444	WORK.
							0.28			
		T	BRICK PER CUBIC FOOT							
		O	MANHOLES			15.8				
		$	CATCH BASINS			17.6				

MANHOLES, CATCHBASINS & CONNECTIONS.

HEGEWISCH SYSTEM CHICAGO.

NASH DOWDLE CO.
CONTRACTOR

24.
AUG-DEC 1909.

LOCATION	SIZE OF SEWER	MANHOLES. No. BUILT	HEIGHT FT	LABOR HOURS	LABOR COST	BRICK No.	BRICK COST	CEMENT BBLS.	CEMENT COST	TOTAL MAT'L	TOTAL	CATCH-BASINS No. BUILT	LABOR HOURS	LABOR COST	MAT'L	TOTAL	CATCH-BASIN CONNECTIONS LABOR HOURS	LABOR COST	MAT'LS	TOTAL	COST PER FOOT.	COST PER FT. OF MAIN SEWER MAN HOLES	CATCH BASINS	C. B. CONN'TNS	TOTAL
134TH ST W	4' 6"	2	58	8	$4.84	713	$3.56	1.4	$0.89	$9.70	$14.54	1	33.5	$14.24		$28.44	.16	$490		$748	$047	$.099	$.097	$.026	$.222
" " E	·	1	"	12	6.28	"	3.56	1.4	.89	9.70	15.98	4	32.7	14.23		28.44	16	495		753	47	043	.304	081	438
AVE	·	3		9	5.32	-	3.56	1.4	.89	9.70	15.02	5	33.0	14.23		28.44	16	493		750	47	068	.212	055	.335
· -	3'-6	10	59	10.4	4.96	727	3.64	1.4	.89	9.78	14.74	20	32.5	14.12		28.32	16	495		753	47	089	.342	091	.512
HOWARD AVE	3-0	10	5.8	8	3.87	713	3.56	1.4	.89	9.70	13.57	14	32.7	13.51		27.71	13	427		685	43	08	.23	056	.366
"	"	6	4.8	10.7	4.55	588	2.94	1.2	.77	8.96	13.51	6	34.3	15.13		29.33	13	490		748	47	089	.19	049	.327
134TH ST	"	4	5.3	19.5	8.28	650	3.25	1.3	.83	9.33	17.61	10	35.1	14.64		28.84	12	390		648	.40	.12	.443	.10	.663
AVE.	"	20	5.3	11.1	4.95						14.76	30	33.8	14.20		28.40	12.7	4.28		6.86	43	088	252	06	.40
136TH ST	2-0	3	6.3	9.3	4.88	775	3.87	1.6	1.02	10.14	15.02	6	36.7	16.10		30.30	19	7.20		9.78	61	.07	.31	10	.48
COMMERCIAL AV.	"	10	5.8	8.8	4.80	713	3.56	1.4	.89	9.70	14.50	12	39.3	15.20		29.40	10	3.66		6.24	.39	.11	.264	.056	.43
AVE.	"	13	6.1	9.0	4.80						14.60	18	38.5	15.50		29.70	13	4.83		7.41	.46	.10	.28	07	.45
ERIE AV.	18"	4	10.2	31.3	11.63	1335	6.68	2.7	1.72	13.65	24.68	4	32.8	11.61		25.81	17	5.61		8.19	.51	.15	.156	.05	.356
ONTARIO AV.	"	5	9.9	36.6	13.01	1395	6.98	2.8	1.78	14.01	27.02	4	37.8	15.10		29.30	15	5.40		7.98	.50	.205	.192	.048	.445
CARONDELET AV.	"	5	9.5	44.0	20.13	1270	6.35	2.5	1.59	13.19	33.32	4	37.5	14.77		28.90	9	3.10		5.68	.36	248	.172	034	.454
HOUSTON AV	"	5	8.0	19.6	9.60	1082	5.41	2.2	1.40	12.06	21.66	4	35.6	13.90		28.10	10	3.81		6.39	.40	.158	164	037	.359
AVERAGE	"	19	8.8	31.1	13.60						26.80	16	35.8	13.90		28.10	12.7	4.42		7.06	.44	.19	.172	043	.405
ERIE AV	15"	6	9.4	27.3	13.61	1408	7.08	2.8	1.78	14.11	27.72	6	33.0	11.80		26.00	17	5.61		8.19	.51	.25	.234	073	.557
SUPERIOR AV	"	5	8.9	40.2	15.18	1220	6.10	2.4	1.53	12.88	28.06	4	31.8	11.90		26.10	9	3.20		5.78	.36	.213	.158	.035	.406
CARONDELET AV.	"	5	8.6	36.4	16.60	1158	5.78	2.3	1.46	12.49	29.09	6	37.7	13.92		28.12	9	3.10		5.68	.36	.215	250	.053	.518
ONTARIO AV	"	5	8.4	26.8	10.82	"	5.78	2.3	1.46	12.49	23.31	6	38.0	15.10		29.30	15	5.40		7.98	.50	.175	.265	.072	.512
HOUSTON AV	"	4	7.7	25.8	12.27	"	5.78	2.3	1.46	12.49	24.76	6	36.0	13.45		27.65	10	3.60		6.18	.38	149	.247	057	.456
BUFFALO AV	"	5	7.6	28.8	13.70	1095	5.48	2.2	1.40	12.13	25.83	4	27.8	11.30		25.50	10	3.50		6.08	.38	144	.153	037	.384
AVERAGE	"	30	8.43	31.0	13.75						26.56	32	34.4	13.25		27.45	12	4.15		6.73	42	.198	220	.054	472
ERIE AV S	12"	6	9.9	29.7	14.76	1496	7.46	3.0	1.91	14.62	29.38	5	35.8	12.40		26.60	17	5.61		7.89	.50	212	.16	048	420
BUFFALO AV	"	9	9.6	33.5	13.40	1310	6.55	2.6	1.65	13.45	26.85	8	28.8	11.41		25.61	10	3.50		6.08	.38	.207	175	.043	425
SUPERIOR AV	"	10	9.2	35.1	14.38	1234	6.18	2.5	1.59	13.02	27.40	8	31.3	11.90		26.10	9	3.10		5.68	.36	212	.16	.035	407
ONTARIO AV	"	9	8.9	29.0	11.75	1245	6.23	2.5	1.59	13.07	24.82	8	37.3	14.85		29.05	15	5.40		7.98	.50	.19	198	055	443
HOUSTON AV	"	3	8.6	22.3	10.20	"	6.23	2.5	1.59	13.07	23.27	2	37.0	14.00		28.20	10	3.55		6.13	.38	.15	.12	026	296
SUPERIOR AV N	"	5	8.4	32.8	11.60	1170	5.85	2.3	1.46	12.56	24.17	8	31.3	11.90		26.10	9	3.10		5.68	.36	.18	.31	067	.557
ONTARIO AV	·	5	6.9	22.6	9.18	982	4.91	2.0	1.27	11.43	20.61	8	37.5	15.08		29.28	10	3.60		6.18	.38	.154	.35	.075	.579
HOUSTON AV	"	11	6.1	20.3	9.05	918	4.58	1.8	1.15	10.98	20.03	12	36.0	13.50		27.70	9	3.10		5.68	.35	.165	.25	.051	.466
CARONDELET AV	"	10	6.0	33.0	15.13	"	4.58	1.8	1.15	10.98	26.11	12	37.7	13.55		27.75	17	5.61		8.19	.51	.196	.25	.074	.520
ERIE AV	"	10	6.1	21.7	10.92	"	4.58	1.8	1.15	10.98	21.90	12	34.8	12.10		26.31	15	3.60		6.18	.38	.164	.235	061	.460
BUFFALO AV	"	5	5.9	21.2	8.81	792	3.96	1.6	1.02	10.23	19.04	8	28.8	11.80		26.00	10	3.50		6.08	.38	.136	.31	072	.508
AVERAGE	"	83	7.92	27.9	12.05						24.15	91	34.3	12.96		27.16	11.9	4.13		6.60	.41	.183	.226	055	.464
AVERAGE OF BRICK SEWERS		46	5.67	10.2	4.93							73	34.5	14.62	14.20	28.80	15.2	4.65		7.23	0.46	.102	.236	.079	.417
" " PIPE	"	132	8.15	29.0	12.62							139	34.5	13.10	14.20	27.30	12.0	4.16		6.74	0.42	.188	.215	.052	.455
GENERAL AVERAGE		178										212	34.5	13.22	14.20	28.30	13.1	4.23	2.58	6.81	0.43	.164	.22	06	0.444

0.28

CATCH-BASIN MAT'L:
9" HALF TRAP & INLET 1.45
C.I. COVER 5.25
CEMENT 2.2 BBLS @ $0.636 1.40
TOTAL $14.20
1100 BRICK @ $5.00 $5.50
60' BM. PLANK BOTTOM } .60
OLD SHEET PILING @ $10.00 }

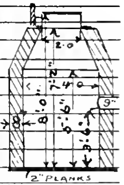
CATCH-BASIN CONNECTIONS MAT'LS:
9" PIPE 16.0 @ $0.145 $2.32
CEMENT 10 JOINTS .18
JUTE .08 } $2.58

THE WOOD BOTTOMS OF THE CATCH BASINS WERE MADE FROM 2"x10"-10'-0" SHEETING ON HAND AFTER COMPLETION OF SEWERS AND WERE CHARGED TO CATCH BASINS AT $10.00 PER M.FT. BM NEW LUMBER WOULD HAVE COST $21.00 ABT. 1300 FT BM. WERE USED.

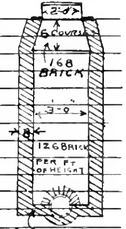
BRICK PER CUBIC FOOT	
MANHOLES	15.8
CATCH BASINS	17.6

REMARKS.

LABOR INCLUDES TERMING OF M'TLS.

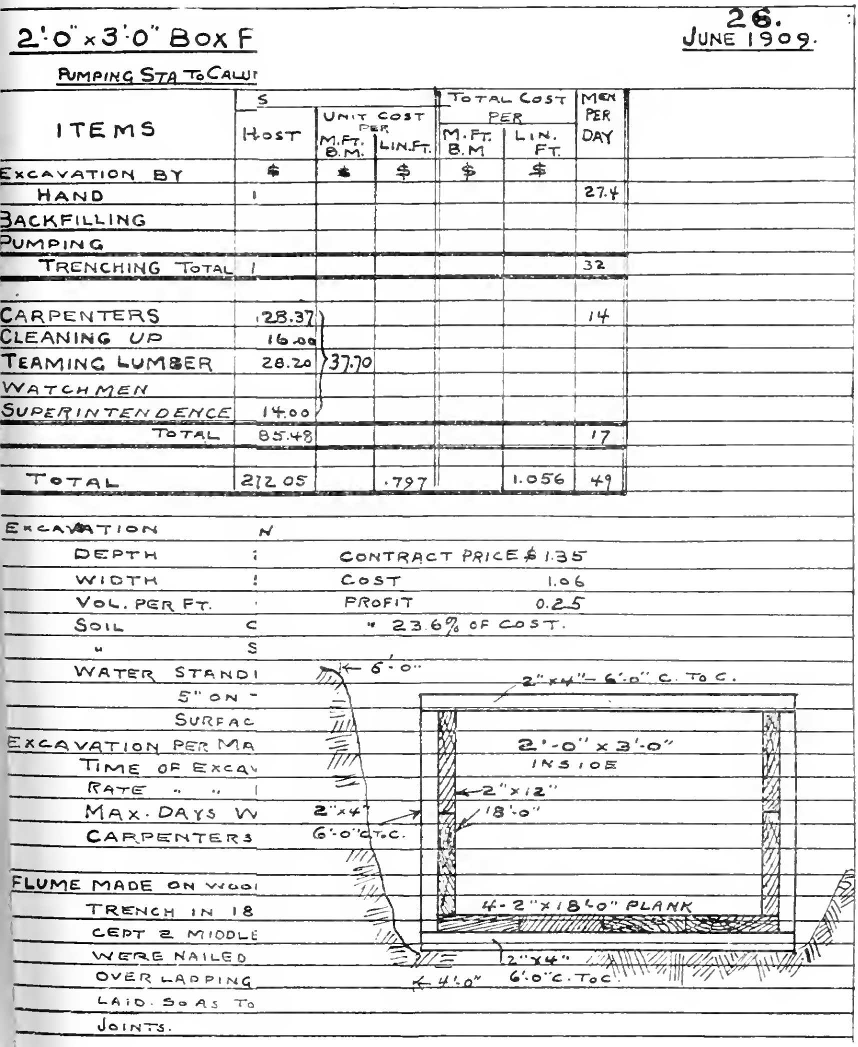


CATCH BASIN



201 BRICK
MANHOLE FOR PIPE SEWER.

HEIGHT OF MAN HOLES GIVEN ARE TOP OF SEWER TO TOP OF BRICK WORK.



2'-0" x 3'-0" Box F

Pumping Sta to Calu

26.
June 1909.

Items	S Host	Unit Cost per M.Ft. B.M.	Unit Cost per Lin. Ft.	Total Cost per M.Ft. B.M.	Total Cost per Lin. Ft.	Men per Day
Excavation by	$	$	$	$	$	
Hand	1					27.4
Backfilling						
Pumping						
Trenching Total	1					32
Carpenters	128.37					14
Cleaning up	16.00					
Teaming Lumber	28.20	37.70				
Watchmen						
Superintendence	14.00					
Total	85.48					17
Total	212.05		.797		1.056	49

Excavation N

Depth : Contract Price $ 1.35

Width : Cost 1.06

Vol. per Ft. Profit 0.25

Soil C " 23.6% of cost.

" S

Water Standi

5" on

Surfac

Excavation per Ma

Time of Excav

Rate " "

Max. Days W

Carpenters

Flume made on wood

Trench in 18

cept 2 middle

were nailed

over lapping

laid so as to

joints.

2'0" x 3'0" BOX FLUME

PUMPING STA TO CALUMET RIVER.

HEGEWISCH
CHICAGO ILL.

NASH DOWDLE CO.
CONTRACTOR

26.
JUNE 1909.

ITEMS	LABOR Hours	LABOR Cost	Work 2248'0"	LABOR PER Wages per Hour	LABOR PER Cu. Yard Hours	LABOR PER Cu. Yard Cost	LABOR PER Lin. Foot Hours	LABOR PER Lin. Foot Cost	MATERIALS Items	MATERIALS Quantity	MATERIALS Price	MATERIALS Cost	Unit Cost per M.Ft. B.M.	Unit Cost per Lin.Ft.	Total Cost per M.Ft. B.M	Total Cost per Lin. Ft.	Men per Day
EXCAVATION BY	¢	$		$		$		$				$	$	$	$	$	
HAND	1228	280.93	1050 Cu. Yds	.229	1.2	.27	.55	.125									27.4
BACKFILLING	76	17.20		226			} .10	} .022									
PUMPING	157	31.40		.20													
TRENCHING TOTAL	1461	329.53		.226			.65	.147									32.
					PER M.	FT B.M.											
CARPENTERS	619	201.20	36,452	325	17.0	5.53	.28	.09	LUMBER	36452'BM	36.00	1328.37					14
CLEANING UP	4	1.10	FT. B.M.	.275					" EXTRA	FREIGHT		16.00					
TEAMING LUMBER	40	15.50		.33			} .07	.01	NAILS	12 KEGS	2.35	28.20	} 37.70				
WATCHMEN	40	7.35		.18					33 LBS. PER	M. FT B.M.							
SUPERINTENDENCE	56	51.90		.925	½ TO EXCAVN.				FREIGHT &	DRAYAGE		14.00					
TOTAL	759	277.05		.364			.35	.123	OFFICE			385.48					17
TOTAL	2220	606.58		.273			1.0	.27				1772.05		.797		1.056	49

EXCAVATION

DEPTH	2'-6"
WIDTH	5'-0"
VOL. PER FT.	0.463 CU. YD.
SOIL	CLAY FOR 500 FT.
"	SAND " 1728 "

WATER STANDING FOR HALF DISTANCE 5" ON TOP OF GROUND. AT ABOUT SURFACE BALANCE OF WAY.

EXCAVATION PER MAN PER DAY	7.7 CU. YDS.
TIME OF EXCAVATION	5. DAYS
RATE " " PER DAY	456.4 FT.
MAX. DAYS WORK	822.0 FT.
CARPENTERS DAYS WORK	472' FT. B.M.

COST PER M. FT. B.M.

LABOR	5.53
SUPT. ½	.71
MATL'S.	37.70
TOTAL	43.94
OFFICE ½	5.30
TOTAL	49.24

COST PER CU. YD EXCAVN

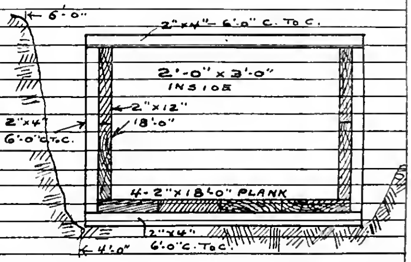
LABOR 1.2 HR	$.27
SUPT. ½	.025
TOTAL	.295
OFFICE ½	.183
TOTAL	.478

CONTRACT PRICE	$1.35
COST	1.06
PROFIT	0.25

" 23.6% OF COST.

THE OFFICE CHARGE IS THAT PERCENTAGE WHICH THIS JOB IS OF THE ENTIRE HEGEWISCH WORK AND REALLY IS TOO HIGH IN PROPORTION TO THE DURATION OF THIS WORK OF 6 DAYS EXTENT.

FLUME MADE ON WOODEN HORSES ALONG EDGE OF TRENCH IN 18'-0" LENGTH COMPLETE EXCEPT 2 MIDDLE BOTTOM PLANK WHICH WERE NAILED IN PLACE ON ACCT OF THEIR OVERLAPPING 6'-0" IN THE SECTION PREVIOUSLY LAID. SO AS TO GIVE STRENGTH BY BREAKING JOINTS. JOINTS.



27.

HAMMER SHOP
CHICAGO DRO

MARCH 1910.

ITEMS OF LAB	ERIALS				TOTAL COST PER	ABSORBING GEN'L EXP. IN TO OPERATIONS	
	NT	PRICE	COST		CU. YD.	CU. YD.	
EXCAVATION BY HAND OF B			$25.00		324		
C			17.00		723		
					560		
PUMPING BY HAND					01		
BACKFILLING					.30		
EXCAVAT			42.00	.09	$0.87	97	
PILE DRIVING					LIN. FT.		
ERECTION & TAKIN			60.00				
SAWING 40' PILES IN 2	FT.	.11	211.20				
UNLOADING PILES FR	TONS	2.25	7.82				
SAWING OFF PILE BUT							
DRIVING 20'-0" P							
			279.02	.152	0.32	.36	
CONCRETE			25.00				
UNLOADING & STORIN	BLS.	.90	306.00				
" SAND	YDS	1.05	136.64				
" STONE	"	1.10	167.11	.99			
" GRAVEL	"	.98	154.18				
LABOR ON FORMS	B.M	20.60	113 00	35			
MAKING & PLACIN			44 00	.21			
			945.93	2.91	5.09	5.73	
BRICKLAYING TEARING DOWN	LS.	.90	6.88		CU. YD.		
DELIVERY OF BRICK-E		.80	100.80				
MAKING & DELIVERY	YDS.	.65	52.40				
" MORTAR BOARDS,	FT.	.14	21.00				
ERECTING & DISMANT		6.00	522.00				
UNLOADING & BEDDING C	'BM	20.60	114.48				
BRICKLAYING 1			18 00				
			889.56	4.38	7.91	18.00	USING ALL NEW BRICK $13.77
GENERAL	ETC.		15.00				
WATCHMAN			122.10				
ENGINEERING							
MANAGEMENT							
			137.10				
GENERAL TOTAL			2293.61				

		HR	$
BRICKLAYING COSTS	BL.	.09	.035
INCLUDING 13000 OLD BRICK	.YD.	.30	.111
PER 1000 BRICK ALL OPENINGS		.394	.156
" SQ. FT. WALL NOT INCLUDED		.24	.091
" CU. FT " " "		.735	.275
" CU. YD " "	OF WORK 20.		

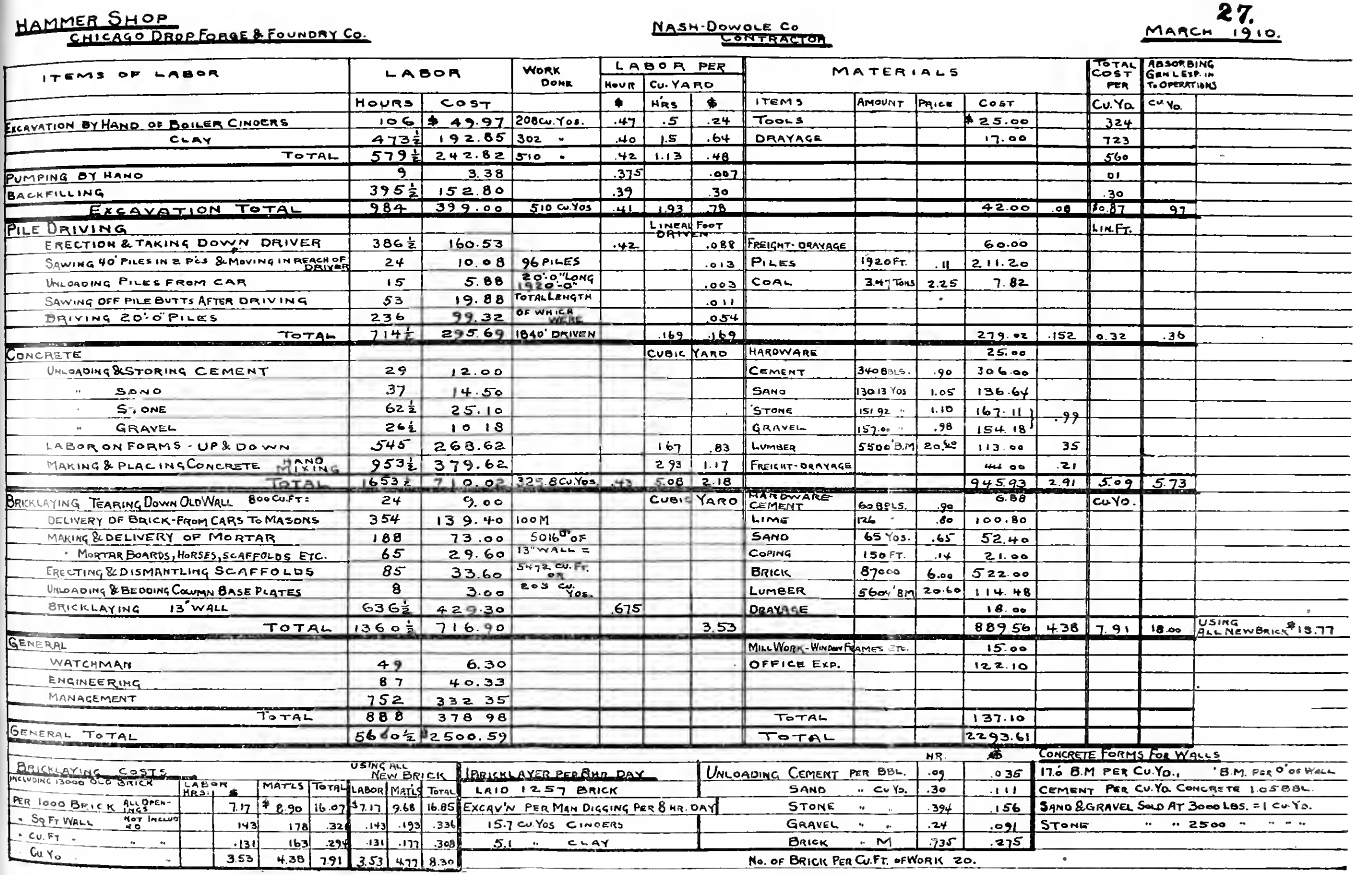
CONCRETE FORMS FOR WALLS

17.0 B.M. PER CU. YD., 'B.M. PER D' OF WALL

CEMENT PER CU. YD. CONCRETE 1.05 BBL.

SAND & GRAVEL SOLD AT 3000 LBS. = 1 CU. YD.

STONE " " 2500 " " " "



HAMMER SHOP
CHICAGO DROP FORGE & FOUNDRY CO.

NASH-DOWDLE CO
CONTRACTOR

27.
MARCH 1910.

ITEMS OF LABOR	LABOR		WORK DONE	LABOR PER			MATERIALS					TOTAL COST PER	ABSORBING GEN'L EXP. IN TO OPERATIONS	
				HOUR	CU. YARD									
	HOURS	COST		$	HRS	$	ITEMS	AMOUNT	PRICE	COST		CU. YD.	CU. YD.	
EXCAVATION BY HAND OF BOILER CINDERS	106	$ 49.97	208 CU. YDS.	.47	.5	.24	TOOLS			$ 25.00		324		
CLAY	473½	192.85	302 "	.40	1.5	.64	DRAYAGE			17.00		723		
TOTAL	579½	242.82	510 "	.42	1.13	.48						560		
PUMPING BY HAND	9	3.38		.375		.007						01		
BACKFILLING	395½	152.80		.39		.30						.30		
EXCAVATION TOTAL	984	399.00	510 CU. YDS	.41	1.93	.78				42.00	.08	$0.87	97	
PILE DRIVING					LINEAL FOOT DRIVEN							LIN. FT.		
ERECTION & TAKING DOWN DRIVER	386½	160.53		.42		.088	FREIGHT-DRAYAGE			60.00				
SAWING 40' PILES IN 2 PCS & MOVING IN REACH OF DRIVER	24	10.08	96 PILES			.013	PILES	1920 FT.	.11	211.20				
UNLOADING PILES FROM CAR	15	5.88	20'-0" LONG 1920'-0"			.003	COAL	3.47 TONS	2.25	7.82				
SAWING OFF PILE BUTTS AFTER DRIVING	53	19.88	TOTAL LENGTH			.011								
DRIVING 20'-0" PILES	236	99.32	OF WHICH WERE			.054								
TOTAL	714½	295.69	1840' DRIVEN		.169	.169				279.02	.152	0.32	.36	
CONCRETE					CUBIC YARD		HARDWARE			25.00				
UNLOADING & STORING CEMENT	29	12.00					CEMENT	340 BBLS.	.90	306.00				
" SAND	37	14.50					SAND	130.13 YDS	1.05	136.64				
" STONE	62½	25.10					STONE	151.92 "	1.10	167.11 }	.99			
" GRAVEL	26½	10.18					GRAVEL	157.00 "	.98	154.18 }				
LABOR ON FORMS - UP & DOWN	545	268.62			1.67	.83	LUMBER	5500' B.M.	20.60	113.00	35			
MAKING & PLACING CONCRETE HAND MIXING	953½	379.62			2.93	1.17	FREIGHT-DRAYAGE			44.00	.21			
TOTAL	1653½	710.02	325.8 CU. YDS.	.43	5.08	2.18				945.93	2.91	5.09	5.73	
BRICKLAYING TEARING DOWN OLD WALL 800 CU. FT.	24	9.00			CUBIC YARD		HARDWARE CEMENT	60 BBLS.	.90	6.88		CU. YD.		
DELIVERY OF BRICK-FROM CARS TO MASONS	354	139.40	100 M				LIME	126 "	.80	100.80				
MAKING & DELIVERY OF MORTAR	188	73.00	5016 □' OF				SAND	65 YDS.	.65	52.40				
" MORTAR BOARDS, HORSES, SCAFFOLDS ETC.	65	29.60	13" WALL =				COPING	150 FT.	.14	21.00				
ERECTING & DISMANTLING SCAFFOLDS	85	33.60	5472 CU. FT. OR				BRICK	87000	6.00	522.00				
UNLOADING & BEDDING COLUMN BASE PLATES	8	3.00	203 CU. YDS.				LUMBER	5604' BM	20.60	114.48				
BRICKLAYING 13" WALL	636½	429.30		.675			DRAYAGE			18.00				
TOTAL	1360½	716.90				3.53				889.56	4.38	7.91	18.00	USING ALL NEW BRICK $13.77
GENERAL							MILL WORK-WINDOW FRAMES ETC.			15.00				
WATCHMAN	49	6.30					OFFICE EXP.			122.10				
ENGINEERING	87	40.33												
MANAGEMENT	752	332.35												
TOTAL	888	378.98					TOTAL			137.10				
GENERAL TOTAL	5660½	$2500.59					TOTAL			2293.61				

BRICKLAYING COSTS INCLUDING 13000 OLD BRICK	LABOR HRS.	$	MAT'LS	TOTAL	USING ALL NEW BRICK LABOR	MAT'LS	TOTAL
PER 1000 BRICK ALL OPENINGS		7.17	$ 8.90	16.07	$7.17	9.68	16.85
" SQ FT WALL NOT INCLUDED		143	178	.326	.143	.193	.336
" CU. FT " "		.131	163	.294	.131	.177	.308
" CU. YD "		3.53	4.38	7.91	3.53	4.77	8.30

BRICKLAYER PER 8 HR. DAY
LAID 1257 BRICK
EXCAV'N PER MAN DIGGING PER 8 HR. DAY
15.7 CU. YDS CINDERS
5.1 " CLAY

	HR.	$
UNLOADING CEMENT PER BBL.	.09	.035
SAND " CU. YD.	.30	.111
STONE " "	.394	.156
GRAVEL " "	.24	.091
BRICK " M	.735	.275

CONCRETE FORMS FOR WALLS
17.6 B.M PER CU. YD., 'B.M. PER □' OF WALL
CEMENT PER CU. YD. CONCRETE 1.05 BBL.
SAND & GRAVEL SOLD AT 3000 LBS. = 1 CU. YD.
STONE " " 2500 " " " "

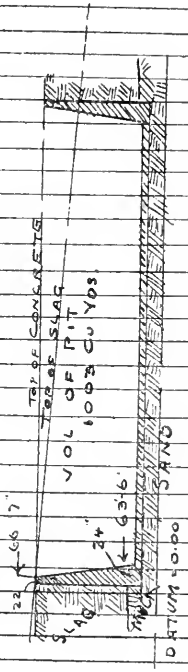
NO. OF BRICK PER CU. FT. OF WORK 20.

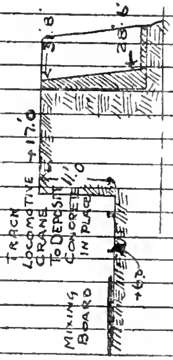
28.

APRIL 1910.

CONCRETE SLA

		COST	COST PER CU. YD.	TOTAL COST PER YD.
	Hc			
EXCAV'N OF SOLID HOT RUN				
BL. FCE SLAG IN MASS	5			
HARD BURNED PEAT MUCK				
& SAND UNDER MUCK				
TOTAL	5			
TRACK RAISING				
CLEANING UP				
TOTAL EXCAVATION	5			
CONCRETE				
UNLOAD'G 1 CAR CEMENT				
" CRUSHED STONE	N			
SCREENING SAND	O			
LOADING ON CARS "	Ln			
UN " "				
FORMS-ERECTION		170.70		
CARPENTERS		7.50		
"				
LABORERS				
ERECTION TOTAL		178.20		
FORMS REMOVAL				
CARPENTERS				
LABORERS				
REMOVAL TOTAL				
FORMS TOTAL				
CONCRETING		ARGE		
FOREMAN		410.32		
CRANEMAN	2	260.33		
LABORERS	2	50.80		
TOTAL	2	15.00		
CONCRETE TOTAL	3	736.45	2.16	
PIPE RAILING		914.65	2.69	4.54
ENGINEERING				
SUPERINTENDENCE				
GENERAL TOTAL				
TOTAL OF PIT	9			
		LABOR		
CONCRETE		FORMS PER	M.FT.	B.M.
FLOOR 98	C	ERECTION	31.0 HRS	$6.10
WALLS 232	"	REMOVAL	29.2 "	5.23
TOTAL 330	"	TOTAL	60.2 "	$11.33





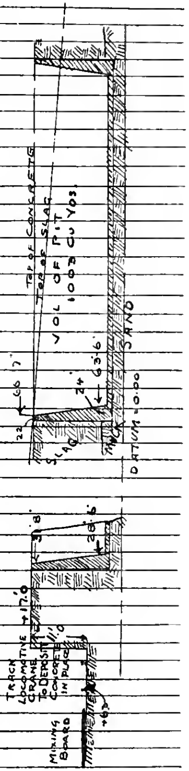
28.

APRIL 1910.

CONCRETE SLAG GRANULATING PIT.

	LABOR COST Hours	LABOR COST Cost $	WORK DONE	HOURLY WAGES $	LABOR PER CUBIC YARD Hours	LABOR PER CUBIC YARD $	MATERIALS	QUANTITY	PRICE	COST	COST PER CU. YD.	TOTAL COST PER YD.
EXCAV'N OF SOLID HOT RUN												
BL FCE SLAG IN MASS	5010	839 88	987 Cu.Yds.	.1675	5.1	.851						
HARD BURNED PEAT MUCK	639	109.33	138 "	.171	4.6	.794						
& SAND UNDER MUCK												
TOTAL	5649	949 21	1125 "	.169	5.0	.845						
TRACK RAISING	160	26.40		.165								
CLEANING UP	120	19.80		.165								
	280	46.20		.165	.3	.049						
TOTAL EXCAVATION	5929	995.41	1125 Cu.Yds.	.167	5.3	.894						
CONCRETE	592	97.68	330 Cu. Yds									
UNLOAD'G 1 CAR CEMENT	108	17.82	CONCRETE	.165	1.8	.29						
" CRUSHED STONE	100	16.50		.165								
SCREENING SAND	144	23.76		.165								
LOADING ON CARS "	150	24.75		.165								
UN " "	90	14.85		.165								
FORMS - ERECTION			2660 Sq.Ft.				LUMBER	7729 FT.B.M.		170.70		
CARPENTERS	31	6.98		.225			HARDWARE			7.50		
"	43	12.90		.30								
LABORERS	165	27.23		.165								
ERECTION TOTAL	239	47.11		.197	0.7	.14				178.20		
FORMS REMOVAL												
CARPENTERS	36	9.45		.263								
LABORERS	190	31.35		.165								
REMOVAL TOTAL	226	40.40		.179	0.7	.12						
FORMS TOTAL	465	87.91		.178	1.4	.26						
CONCRETING							SAND - BURNT CAST HOUSE SAND - NO CHARGE					
FOREMAN	85	21.68		.255			CEMENT	446 BBLS	92	410.32		
CRANEMAN	84	27.30		.325			STONE	338.6 Yds.	87½	260.33		
LABORERS	2306	380.49		.165			LUMBER	2400' B.M		50.80		
TOTAL	2475	429.47		.1725	7.5	1.30	FREIGHT			15.00		
CONCRETE TOTAL	3532	615.06	330 Yds.	.175	10.7	1.85				736.45	2.16	
PIPE RAILING	96	18.96		.1975			TOTAL CONCRETE			914.65	2.69	4.54
ENGINEERING	32	29.65		.926								
SUPERINTENDENCE	NO	CHARGE										
GENERAL TOTAL	128	48.60		.38								
TOTAL OF PIT	9689	$1658.97		.171								

CONCRETE		LABOR FORMS COST PER CU.YD				LABOR FORMS PER SQ. FT. OF CONCRETE			LABOR FORMS PER M.FT. B.M.		
FLOOR 98	Cu. Yds.	OF WALLS (FLOOR NOT USING				ERECTION	0.09 HR	$0.018	ERECTION	31.0 HRS	$6.10
WALLS 232	" "	FORMS) ERECTION	1 HR.	$0.20	TOTAL	REMOVAL	0.09 "	0.015	REMOVAL	29.2 "	5.23
TOTAL 330	" "	REMOVAL	1 "	0.17	2.0 HRS $0.37	TOTAL	0.18 "	0.033	TOTAL	60.2 "	$11.33



LABOR COS

HEGEWI

AUG. - NOV. 1909.

SIZE OF SEWER	KIND OF SEWER	LOCATION	TAL COST	M.H., C.B., & C.B.CONNS ONLY	RATE OF WAGES PER MAN PER HOUR	COST OF SEWER ONLY, ON BASIS OF $0.30 PER HOUR	
4'6"	BRICK	134TH ST	$ 7.71	$ .08	$.291	$	SEWER CARRIED UNDER 6 R.R. TRACKS
"	"	"	4.67	.28	.40		BRICK SEWERS
"	"	" AVERA	6.35	.15	.317		STEAM SHOVEL 36313 HRS $15673.01
3'-6"	"	"	4.46	.15	.405		HAND WORK 37191 " 12194.10
3'-0"	"	HOWARD AVE	4.06	.16	.473		ST. S. WORK $.433 PER HOUR
"	"	"	9.60	.16	.343		HAND " $0.327 " "
"	"	134TH ST	4.16	.33	.34		
"	"	AVERAG	3.68	.20	.406		
2'-0"	"	136TH ST	2.41	.26	.348		
"	"	COMMERCIAL	2.07	.21	.338		
"	"	AVERAG	2.16	.20	.342		
18"	PIPE	CARONDELET	2.23	.07	.306	2.12	
"	"	HOUSTON	3.65		.257	4.27	
"	"	AVERAG	2.34	.05	.30	2.29	
"	"	ERIE AVE	1.03	.18	.30	.85	
"	"	ONTARIO AVE	1.29	.17	.28	1.22	
"	"	CARONDELET	1.69	.36	.32	1.25	INCLUDES ASSEMBLING NEW SYSTEM OF WELL POINTS
"	"	HOUSTON AVE	.81	.21	.32	.57	
"	"	AVERAG	1.16	.22	.31	.91	
15"	"	ERIE AVE S	1.04		.31	.75	10" MACADAM
"	"	SUPERIOR AV	.96		.274	.84	
"	"	CARONDELET A	1.07		.327	.72	
"	"	ONTARIO A	1.08		289	.83	
"	"	HOUSTON A	.84		.33	.53	
"	"	BUFFALO A	1.09		292	.93	
"	"	AVERAGE	1.02	25	.30	.77	
12"	"	ERIE AVE SOU	1.08		.266	.99	6" MACADAM
"	"	BUFFALO AVE.	1.11		.28	.97	
"	"	SUPERIOR AVE.	.89		.297	.69	
"	"	ONTARIO AVE.	.91		.296	.74	4" MACADAM
"	"	HOUSTON AVE	.90		.33	.63	
"	"	SUPERIOR AVE	.88		.298	.61	
"	"	ONTARIO AVE	.96		.315	.65	
"	"	HOUSTON AVE	.70		311	.51	
"	"	CARONDELET A	.92		.314	.46	10" MACADAM PAVEMENT
"	"	ERIE AVE	.68		.302	.44	
"	"	BUFFALO AVE	.64✓		.32	.38	
"	"	AVERAG	.875	.222	.30	.653	
"	"	HOUSTON AVE					
		TOTAL					
		"					
		"					

LABOR COSTS PER LINEAL FOOT OF SEWER NASH DOWDLE CO. CONTRACTOR AUG. - NOV. 1909
HEGEWISCH, CHICAGO ILL.

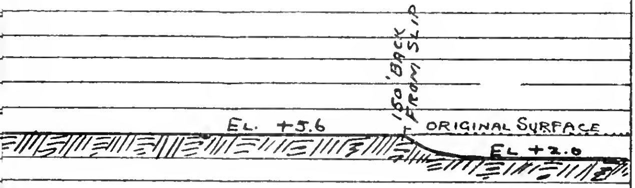
SIZE OF SEWER	KIND OF SEWER	LOCATION	METHOD OF EXCAV'N	METHOD OF PUMPING	AVE DEPTH FT.	LENGTH	LABOR COST PER LIN. FOOT OF SEWER: SEWER		MANHOLES		CATCH BASINS		C.B. CONN'T'NS		TOTAL		M.H., C.B., & C.B. CONN'TS ONLY	RATE OF WAGES PER MAN PER HOUR	COST OF SEWER ONLY, ON BASIS OF $0.30 PER HOUR	
							HOURS	$	H'RS	$ COST	HRS	$ COST	HOURS	$	HOURS	COST				
4'6"	BRICK	134TH ST	HAND WORK	TRENCH PUMPING	12.0	373	26.5	7.63		.026		.038		.013	26.5	$ 7.71	$ .08	$.291	$	SEWER CARRIED UNDER 6 R.R. TRACKS
"	"	"	STEAM SHOVEL	"	12.7	293	11.0	4.39		.017		.206		.053	11.6	4.67	.28	.40		BRICK SEWERS
"	"	" AVERAGS		"	12.3	666	19.6	6.20		.024		.107		.015	20.0	6.35	.15	.317		STEAM SHOVEL 36313 HRS $15673.01
3'6"	"	"	ST SHOVEL	"	11.3	1657	10.4	4.21		.03		.176		.06	11.0	4.46	.15	.405		HAND WORK 37191 " 12194.10
3'0"	"	HOWARD AVE	"	"	11.4	1700	8.2	3.90		.022		.106		.035	10.5	4.06	.16	.473		ST. S. WORK $.433 PER HOUR
"	"	"	HAND	WELL POINTS	11.0	932	7.2	2.44		.028		.097		.031	7.6	2.60	.16	.343		HAND " $0.327 " "
"	"	134TH ST	BOTH	TRENCH PUMPING	10.5	653	11.5	3.83		.051		.223		.06	12.3	4.16	.33	.34		
"	"	AVERAGE			11.0	3285	8.6	3.48		.03		.13		.04	9.1	3.68	.20	.406		
2'0"	"	136TH ST	HAND WORK	WELL POINTS	10.0	581	6.3	2.15		.025		.165		.074	7.0	2.41	.26	.348		
"	"	COMMERCIAL AVE	ENTIRELY	"	9.7	1336	5.6	1.86		.038		.138		.033	6.1	2.07	.21	.338		
"	"	AVERAGE	"	"	9.9	1917	5.8	1.96		.033		.145		.045	6.4	2.16	.20	.342		
18"	PIPE	CARONDELET AVE	"	TRENCH PUMPING	10.2	247	7.2	2.16		.068					7.3	2.23	.07	.306	2.12	
"	"	HOUSTON "	"	"	8.8	22	14.3	3.65							14.2	3.65		.257	4.27	
"	"	AVERAGE	"	"	10.0	269	7.7	2.29							7.9	2.34	.05	.30	2.29	
"	"	ERIE AVE	"	WELL POINTS	11.0	661	3.0	.85		.078		.07		.035	3.44	1.03	.18	.30	.85	
"	"	ONTARIO AVE	"	"	10.6	664	4.2	1.12		.043		.09		.033	3.58	1.29	.17	.28	1.22	
"	"	CARONDELET AVE	"	"	10.2	413	4.0	1.33		.195		.142		.03	3.36	1.69	.36	.32	1.25	INCLUDES ASSEMBLING NEW SYSTEM OF WELL POINTS
"	"	HOUSTON AVE.	"	"	8.8	639	2.0	.60		.096		.087		.022	2.54	.81	.21	.32	.57	
"	"	AVERAGE	"	"	10.2	2377	3.24	.94	0.2	.093	.24	.093	.09	.03	3.5	1.16	.22	.31	.91	
15"		ERIE AVE SOUTH	"	"	10.0	669	2.8	.763		.122					3.44	1.04		.31	.75	10" MACADAM
"	"	SUPERIOR AVE.	"	"	9.5	660	3.0	.762		.115					3.6	.96		.274	.84	
"	"	CARONDELET AVE.	"	"	9.2	672	2.7	.786		.124					3.37	1.07		.327	.72	
"	"	ONTARIO AVE	"	"	9.0	663	3.2	.748		.10					3.74	1.08		289	.83	
"	"	HOUSTON AVE.	"	"	8.3	669	1.9	.586		.10					2.55	.84		.33	.53	
"	"	BUFFALO AVE	"	"	8.2	661	3.3	.90		.104					3.8	1.09		292	.93	
"	"	AVERAGE	"	"	9.0	3994	2.8	.77	.22	.11	.28	.11	.1	.03	3.4	1.02	.25	.30	.77	
12"	"	ERIE AVE SOUTH	"	"	10.5	831	3.6	.875	THESE QUANTITIES PER						4.1	1.08		.266	.99	6" MACADAM
"	"	BUFFALO AVE. "	"	"	10.2	1163	3.5	.908	LIN. FT. OF MAIN SEWER						4.0	1.11		.28	.97	
"	"	SUPERIOR AVE. "	"	"	9.8	1298	2.4	.685	BEING SO INCONSIDERABLE						3.0	.89		.297	.69	
"	"	ONTARIO AVE. "	"	"	9.5	1173	2.6	.733	THE FIGURES FOR EACH						3.1	.91		.296	.74	4" MACADAM
"	"	HOUSTON AVE "	"	"	9.2	455	2.9	.693	INDIVIDUAL STREET ARE						2.7	.90		.33	.63	
"	"	SUPERIOR AVE N.	"	"	9.0	670	2.2	.610	NOT WORKED OUT BEING						2.9	.88		.298	.61	
"	"	ONTARIO AVE "	"	"	8.0	668	2.3	.680	OF NO PERMANENT VALUE.						3.0	.96		.315	.65	
"	"	HOUSTON AVE "	"	"	7.5	1337	1.8	.524							2.3	.70		311	.51	
"	"	CARONDELET AV. "	"	"	6.7	1332	2.3	.440							3.0	.92		.314	.46	10" MACADAM PAVEMENT
"	"	ERIE AVE "	"	"	6.6	1340	1.6	.443							2.2	.68		.302	.44	
"	"	BUFFALO AVE "	"	"	6.5	668	1.4	.400							2.0	.64		.32	.38	
"	"	AVERAGE	"	"	8.3	10958	2.4	.653	.18	.084	.28	0.11	.1	.034	2.94	.875	.222	.30	.653	
"	"	HOUSTON AVE S.	"	TRENCH PUMPING	10.0	25	12.7	3.13												
		TOTAL	BRICK		11.2	7525														
		"	PIPE		9.0	17623														
		"				25148														

F
732

SCRAPER EXC

30.
JUNE 1910.

ITEMS OF WORK	
	D 350.0
PLOWING GROUND	GRAVEL WITH CLODS OF
TEAMS	RED THROUGHOUT
LABORERS	ACIOUS MATERIAL TO PLOW
TOTAL	
SCRAPER WORK	
TEAMS	
MEN LOADING	
" DUMPING	
TOTAL	
FILLING IN "SLIP"	
TEAMS PLOWING	
MEN "	
" SHOVELLING	
TOTAL	TO SCRAPE FROM THE ORIGINAL
FOREMAN & WATERBOY	6 DOWN TO WATER BUT AT EL +2.0
TOTAL LABOR	ORK BECAME MIRY. THE SPOIL WAS
MATERIALS	THE EDGE OF AN OLD SLIP FOR A
6 WHEELED SCRAPERS	O AND AS IT PILED UP WAS THROWN
6 SLIP "	TER BY PLOWING FURROWS THE LENGTH
2 PLOWS	ANK.
TENT FOR STABLE	
LUMBER	
FREIGHT	
TOTAL	
TOTAL EXPENSE	
THE TENT COST $210.	
& WAS SOLD FOR $125.	
ONE SCRAPER TEAM	
INCLUDING 2 "SNAP"	



30.

SCRAPER EXCAVATION — **NASH DOWDLE CO. CONTRACTOR.** — **JUNE 1910.**

ITEMS OF WORK	LABOR		WORK DONE	RATE OF WAGES PER H'R	COST PER CU YD.
	HOURS	COST		$	$
PLOWING GROUND		$			
TEAMS	180	131.05		728	.0245
LABORERS	243	63.00		36	012
TOTAL	423	194.05		458	.0365
SCRAPER WORK					
TEAMS	1371½	993.00		.751	.186
MEN LOADING	243	80.00		329	015
" DUMPING	243	68 00		.28	.013
TOTAL	1867½	1141.00	5316 Cu. Yds	.611	214
FILLING IN "SLIP"					
TEAMS PLOWING	180	130.80		.726	
MEN "	270	63.00		234	
" SHOVELLING	165½	43.45		.263	
TOTAL	615½	247 25		403	.0465
FOREMAN & WATERBOY	306	128.00		.42	.023
TOTAL LABOR	3412.	1710.30		.503	$0.32
MATERIALS		$			
6 WHEELED SCRAPERS		72.00			
6 SLIP "		27.00			
2 PLOWS		42.00			
TENT FOR STABLE		85 00			
LUMBER		14.00			
FREIGHT		60.00			
TOTAL		$300.00			.056
TOTAL EXPENSE		$2010 30	5316 Cu. Yds		$0.376

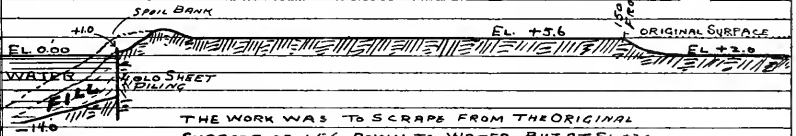
THE TENT COST $210.00 & WAS SOLD FOR $125.00 } NET COST $85.00

ONE SCRAPER TEAM AVERAGED 35.0 CU. YDS PER 9 HOUR DAY INCLUDING 2 "SNAP" TEAMS PULLING TO START & LOAD.

REMARKS

AVE LENGTH OF HAUL OF LOAD 350.0

SOIL - AMIXTURE OF SAND & GRAVEL WITH CLODS OF CLAY CLOSELY SCATTERED THROUGHOUT MAKING A TOUGH TENACIOUS MATERIAL TO PLOW AND DIG.



THE WORK WAS TO SCRAPE FROM THE ORIGINAL SURFACE OF +5.6 DOWN TO WATER BUT AT EL +2.0 TO +2.5 THE WORK BECAME MIRY. THE SPOIL WAS DUMPED ALONG THE EDGE OF AN OLD SLIP FOR A LENGTH OF 300.0 AND AS IT PILED UP WAS THROWN INTO THE WATER BY PLOWING FURROWS THE LENGTH OF THE SPOIL BANK.

Diagrams of excavation cost curves per cubic yard and per cubic foot.

In general, the great irregularity of the plotted points compared with the curves shows more strongly than in any other way the inadvisability of attempting to make generalized statements of such work on account of the diverse conditions, of ground water, manner of pumping, manner of excavating and of backfilling. But in the case of the 8 in., 10 in. and 12 in. pipe sewers, where the only variable in general was the depth, the plotted points fall very close to a smooth curve.

Sheeting and bracing trenches.

The stringers used were generally 3 in. by 12 in. or 4 in. by 12 in. and 16 ft. in length of long leaf yellow pine.

Braces were generally 6 in. by 6 in. yellow pine. In Gary, where the country was covered by a growth of various oaks, mainly small trees, many braces were cut from the standing timber. These braces were usually 3 in. to 5 in. diameter. Dunn trench screws are highly advantageous on account of ease of placing and removing the braces and of keeping them tight.

Two sketches are given for making up a bill of material for a system of well points for use in sandy localities. Galvanized pipe will pay as compared with black pipe. The men will take better care of it, it keeps better in storage, and has a higher selling value than black pipe.

The various tables of costs are self-explanatory.

The hammer shop of the Chicago Drop Forge & Foundry Co., is a building constructed entirely under the Chicago union scale of wages. This sheet shows how an analyzed comprehensive statement of cost of a large number of different kinds of work can be kept according to the method described.

The sketches of *forms* for brick and concrete sewers have stood the test of time and use satisfactorily.

The 36 in. circular brick sewer from Clarke to Pine, Indiana, was built as a pioneer prior to starting buildings across the dunes and sloughs between the Calumet River and Lake Michigan. The profile shows a most forbidding piece of work to be undertaken. The sloughs were full of water with rank vegetable growth. The ridges were heavily wooded. The time of work was mid-summer when the heat and the lack of wind in the thick sloughs made work exhausting. The locality was inaccessible and most of the men walked to and from the work to Gary—a distance each way of 4 miles; labor was hard to get, yet the cost sheet does not show an excessive labor cost.

Pile Driving.

Four thousand and seventeen (4,017) feet of sand trench, 10 ft. deep, was sheeted to carry a steam shovel over the trench; 2-in. by 10 in.-14-ft. hemlock and yellow pine sheeting was used.

Triple-lap sheeting was made by nailing on 1-in. by 6-in.-12 ft. hemlock sides.

The cost of making the sheeting ready for driving was 8.8 hours of labor at $2.63 per 1,000 ft. B. M. with labor at $0.31 per hour. The work was nailing on the side pieces, pointing the driving end, and cutting the hammer end to 8 in. in width to permit the use of a steel driving cap.

The total labor cost, including the making of the sheeting in place, with labor at $0.30 per hour, was:

	Per M. Ft. B. M.	**Per Lin. Ft. of Trench**	**Per Sq. Ft. of Penetration Trench Side of Sheeting**
Hours of labor	21.9	1.4	0.12
Cost of labor	$6.56	$0.422	$0.035

A pile driver having two sets of leads complete was built for this work at a cost of about $600.00 for labor and material, excluding the double-drum hoisting engine. The leads and sheaves for the hammer line were fastened on the deck timbers so that when the width of the trench was reduced at a change in the size of the sewer, the leads were moved in towards the center line of the machine. This change took an hour and a half to make.

The sheet piling was pulled by a machine consisting merely of a platform to carry a hoisting engine and an A-frame carrying two sheaves. Over these sheaves two lines ran from the engine, on the free end of which was a few feet of ½-in. chain and a hook with which to pull the sheeting.

This machine would be manned by a pick-up crew of engineman, fireman, and four laborers, who would pull, in an hour and a half to two hours' work, all of the sheeting corresponding to a day's progress of the work, which would be from 130 to 160 ft. The average rate of wages per hour was $0.30. The amount, average of work was:

	Per M. Ft. B. M.	**Per Lin. Ft. of Trench**
Hours of labor	3.72	0.24
Cost of labor	$1.11	$0.07

One disadvantage of such sheeting was that the 1-in. side pieces had a short life, requiring renewing after about four times of use. The loss of the center pieces from hard driving and even though used nine times was very little. The pulling chain was rather severe upon the sheeting, as it was liable to cut into the wood. At the close of the work the sides were stripped off and half of the 2-in. by 10-in. pieces were sawed up for catch-basin bottoms, which otherwise would have required the purchase of new lumber. The total waste of sheeting was about one-fourth and the remainder was shipped to another job.

Hand driven sheeting of 2-in. by 10-12 ft. long is best driven in sand by a combination of hand mauling and the use of the water jet. Employing labor at $0.314 per man per hour, the expense of this work for 1,102 ft. of trench was:

	Per M. Ft. B. M.	Per Lin. Ft. of Trench	Per Sq. Ft. Penetration
Hours of labor	11.9	0.973	0.042
Cost of labor	$3.70	$0.305	$0.013

FOUNDATION PILE DRIVING.

This statement is the record of a large piece of work carried on by the contractor with great vigor. At times as many as nine pile drivers were at work simultaneously.

In foundation pile driving, where piles are driven in clusters, the general level of the ground will be higher after driving than it was before. This swell or rise of the level will cause an extra amount of excavation for the placing of the footing concrete around the pile tops.

Careful levels were taken over an area in which 1,570 piles were driven 2 ft.-6-in. centers. The piles were 35 ft. long, having 12-in. tops and 7-in. points. The swell of the ground amounted to 1.5 ft. in height, or 8.3 cu. ft. net measurement of the earth per pile, or 0.28 cu. ft. of pile penetration. Inasmuch as the volume of the piles below the original surface averaged 14.1 cu. ft., the consolidation of the earth amounted to 5.8 cu. ft. per pile. The soil consisted for about 10 ft. of a mixture of loose sand, gravel, and clay. Below this was a moderately soft blue clay.

At the job for the hammer shop, a drop hammer was used, weighing 3,000 lb. In fact, the same driver and crew forman did this work as the drop-hammer driving, for which costs are given in Table 22. But the soil was clay, whereas the first 10 to 12 ft. was sand, in the other case mentioned in Table 22.

From points of view of speed, economy, and excellence of driving, the comparison between drop and steam hammers is strongly in favor of steam hammers.

TABLE 21.

FOUNDATION PILES.

Chicago Drop Forge & Fdy. Co.
Nash Dowdle Co.—Contractor.

	Hours	Cost	Cost Per Lin. Ft.	Material
Erection and dismantling driver....	386.5	$160.53	$0.088	
Unloading and sawing piles in two.	39	15.96	0.016	
Driving piles	236	99.32	0.011	96 piles
Sawing pile tops to grade.........	53	19.88	0.054	20 ft. long
				Crew 10 men
Total	714.5	295.69	0.169	
Freight, supplies and piles, cost...		279.02	0.152	
Total cost		574.71	0.321	

Soil, hard clay; hammer used, 3,000-lb. drop hammer.

TABLE 22.

FOUNDATION PILES.

Great Lakes Dredge & Dock Co., Contractor.

	No. 1 Vulcan Steam Hammer		3000-lb. Drop Hammer	
Total number of piles..................	10,417		519	
Total length of piles..................	373,715	feet	17,855	feet
Total length of pile penetration........	358,090	“	16,817	“
Average length per pile................	36.0	“	34.4	“
Average length of piles undriven......	1.5	“	2.0	“
Average day's work for 1 driver........	277	days	30	days
Average piles driven per day...........	37.7	piles	17.3	piles
Average piles driven per day...........	1,349.2	lin. ft.	595.2	lin. ft.
Average piles penetration per day.......	1,296.2	lin. ft.	560.6	lin. ft.
Crew per driver.......................	10	men	9	men
Auxiliary men per driver per day.....	8	men	6	men
Total crew per driver per day.........	18	men	15	men
Crew time 8 hr. day..................	2,770	days	270	days
Auxiliary time 8 hr. day..............,	1,634	“	180	“
Total time 8 hr. day..................,	4,986	“	450	“
Daily pay roll crew....................	$34.00		$30.60	
Auxiliaries ....,	19.75		15.25	
Total	53.75		45.85	

Unit Cost	Lin. Ft. of Pile	Lin. Ft. Penetration	Lin. Ft. of Pile	Lin. Ft. Penetration
Labor	$0.04	$0.042	$0.077	$0.082
Saving pile butts	0.003	0.003	0.003	0.003
Total labor	0.043	0.045	0.08	0.085
Supplies and repairs est..............	0.01	0.01	0.015	0.015
Piles	0.125	0.125	0.12	0.12
Total "field" expense.................	0.178	0.180	0.215	0.220

In addition, a proportional share of local general office and yard expense and the general office expense, should be added.

The economy of a steam-hammer as compared with a drop-hammer pile driver is very great, as shown in the table.

In sawing off pile-butts two saw filers kept the saws sharp for the gang of sawyers. Of the sawyers, a pair would cut 40 to 60 mixed wood piles per day at a cost per pile of $0.10 to $0.12.

The auxiliaries were employed in making runways and unloading piles from cars which were delivered at the edge of the work, a team and two men hauling piles to the more inaccessible drivers.

The ordinary pile driver crew was composed of men as follows:

Foreman	$0.58¾	per	hr.	9 hrs.	$ 4.80
1 engine runner	0.55	"	"		4.40
1 fireman	0.37½	"	"		3.00
1 winchman	0.45	"	"		3.60
1 leadsman	0.45	"	"		3.60
3 groundmen or deckhands	0.40	"	"		9.60
1 coalpasser	0.25	"	"		2.00
1 pile hooker and trimmer	0.37½	"	"		3.00
Total labor of crew					$34.00
Auxiliaries 6 men					15.00
Proportion of pumping station labor, supplying water for jetting					2.00
Field superintendence					2.75
Total labor					$53.75

Marine pile driving, as reported in Table 23, was all within a protected harbor shielded from the heavy waves of the open lake, so but little time was lost by rough seas.

In the delivering of piles from cars to scows, a large part of the labor was done by steam devices, but it is considered as being equal to the expense of six men all of the time the marine driving was going on.

The soil was sandy for a few feet and then it was a moderately soft clay.

The piles stood out of the water on an average of 12 ft. per pile undriven. A tug was occupied about one-third of a day per driver in towing out and back to the yard.

A drop hammer of 3,500 lb. weight was generally used, being attached continuously to the hoisting rope. Each driver had two scows for piles, one on the work and one at the yard being loaded with piles.

The following table shows the cost of this kind of work.

TABLE 23.

Marine Pile Driving.

By Great Lakes Dredge & Dock Co.

Number of piles driven	9,896	
Length of piles driven	326,295	lin. ft.
Length of pile penetration	207,816	" "

Average of piles	33	“ “
Average of piles driven	21	“ “
Total days' work and driver	137	
Piles per day work and driver	72.2	
Piles per day work and driver	2,380	lin. ft.
Penetration per day work and driver	1,516	“ “
Crew of driver	10	men
Auxiliaries driver	6	“
Total men per driver	16	“
Total crew time	1,370	days
Total auxiliaries time	822	“
Total	2,192	“

Pay roll per day:

Tug service	$15.00
Crew	34.00
Auxiliaries	19.75
Total	$68.75

Costs	Lin. Ft. of Piling		Lin. Ft. of Penetration
Labor	$0.029		$0.0453
Supplies and repairs	0.015	Estimate	0.0235
Piles	0.125	“	0.1962
Total “field” expense	$0.169		$0.265

Triple lap sheeting was driven for three foundation pits. The upper 15 ft. of ground is sand, below which is a soft clay. Through the sand, driving was assisted by using a water jet. The expense of this work is given in Table 24.

TABLE 24.

Foundation Sheet Pile Driving.

Piling driven	405 pieces	Moving out and off job	5 days	$227.50
“ “	9,291 lin. ft.	Driving	19 “	679.00
“ “	83,622 ft. B. M.			
		Total	24 “	$906.50

Unit Cost of Labor.

$2.24 per pile.
0.098 “ lin. ft.
10.84 “ M. ft. B. M.

Two No. 1 Vulcan steam hammer drivers were used. Hence the item of moving on and off the work was somewhat high. The average rate of pay per man per 8-hour day was $3.50. including men nailing the sheeting planks together, the average size of screw per machine was from ten to twelve men. Including supplies and repairs, the expense per machine per day was approximately $50.00, whereas the labor as above given amounted to $37.77 per day.

At the same place 717 pieces of 9-in. by 12 in. 28 ft. triple-lap sheeting were driven. This formed a subaqueous front of a concrete-topped wharf. Table No. 25 gives the cost of this work.

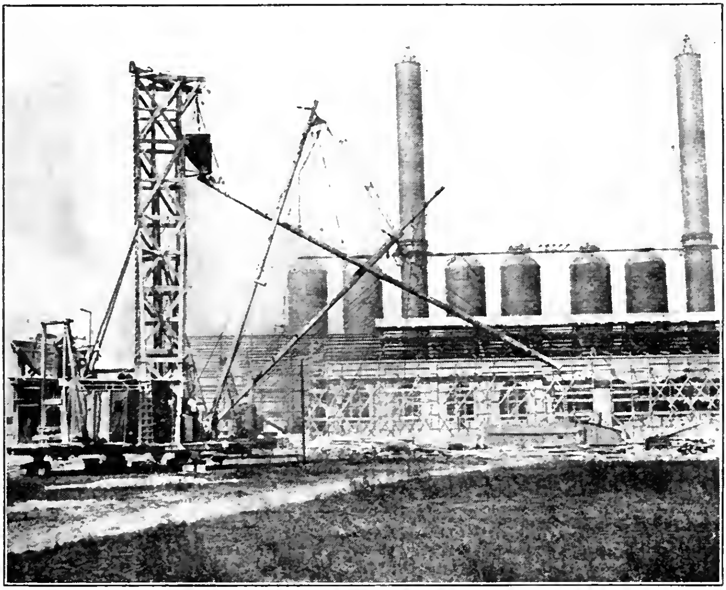
TABLE 25.

WHARF SHEET PILING.

Time occupied in the work, 29½ days.

Piling driven.
405 pieces.
14,340 ft. driven in ground.
180,784 ft. B. M. of lumber.

Towing, ⅓ of cost of	30 days	@ $10.00	$ 300.00
Making sheeting	75 "	@ 3.00	225.00
Driving	285 "	@ 3.50	997.50
Pulling	10 "	@ 3.50	35.00
Total	370 days		$1,557.50
Labor cost per piece			$2.17
" " " lin. ft. driven			0.109
" " " 1,000 ft. B. M			8.62



Concrete Mixer and Delivery Mechanism for Foundation Work.

Concrete.

In addition to the concrete costs to be found in the previous pages, the labor costs for building the concrete foundations of a new blast furnace plant in the vicinity of Chicago are given. In explanation of the tabulated costs it may be said that all concrete was machine-mixed; Smith and Ransome type machines were used. Most of the concrete was discharged onto the site of the work by a pivoted 8-in. diameter flexible iron pipe, carried by ropes hung from swinging booms, carried by a movable

CONCRETE LABOR COSTS

FOUNDATIONS FOR A BLAST FURNACE PLANT

34.

1910 II

LOCATION OF WORK	CHARACTER OF WORK	VOLUME OF CONCRETE	SURFACE OF CONCRETE COVERED BY FORMS PER CU. YD.		DAYS WORK		TOTAL LABOR DAYS OF 9 HOURS	CONCRETE PLACED PER DAY OF		LABOR COST PER CU. YD.		
		CU. YDS.	TOTAL CONCRETE	EXCLUDING FOOTG	TOTAL TIME	TIME OF CONCRETG		TOTAL TIME	CONCRETING DAYS	1 MAN PER DAY OF 9 HRS.	$	
			SQ. FT.	SQ. FT.								
BLAST FURNACES & CAST HOUSES	MASSIVE WORK	10809	7.57	8.54	110	88	5020	98.5	123	.46	1.43	SUMMER WEATHER
HOT BLAST STOVES & BOILERS	" "	10064	9.74	16.1	79	57	3977	128	172	40	1.24	" "
POWER HOUSE	LIGHT PIERS & FLOORS WITH SOME MASSIVE PIERS	3733	12.8	14.4	75	36	2310	49.6	103.5	.62	2.02	WINTER "
CASTING MACHINE BLDG	LIGHT PIERS & WALLS	1225	14.2	-	17	14	922	72.	87.5	.75	2.32	SPRING "
WHARF	MASSIVE WORK	3344	6.1	-	24	20	1290	139	167.5	.39	1.21	WINTER & SPRING "
TRESTLE	MODERATELY HEAVY PIERS	6971	8.69	14.7	70	62	3900	100	113	56	1.74	WINTER "
TOTALS AND AVERAGES		36,146	9.0	13.0	375	277	17419	96.5	130.	.482	1.49	

MAX. OUT PUT 11500. CU. YDS PER MONTH - 3 MIXERS

LABOR OF PLACING 500,000 LBS OF STEEL REINFORCEMENT INCLUDED - (NONE IN CAST'G MACH.) 14 LBS PER CU. YD.

LABOR OF ERECTING & DISMANTLING PLANT FOR HANDLING CONCRETE IS INCLUDED.

RATE OF WAGES $0.344 PER MAN PER HOUR INCLUDING ENTIRE FORCE.

CONCRETE WAS MACHINE MIXED & DELIVERED, EXCEPT FOR THE TRESTLE WHERE DELIVERY WAS MADE BY HAND PUSHED NARROW GAUGE "KOPPEL" ONE CU. YD. TIP CARS.

tower. The concrete was discharged from the mixer into a cubic yard steel plate hoist which, being lifted in a tower to a height of 65 feet, discharged its contents into the pipe. To use this apparatus the concrete must be mixed liquid enough to run easily. A defect of machines of this type is that segregation of the stone from the mortar takes place to the extent that a couple of men are constantly occupied in working the stone back into the general mass.

Where the concrete was not placed by tower devices as above, the mixers discharged into Koppel steel narrow-gauge cars (which were hand-pushed), or else into cubic yard bottom-dumping buckets, which were handled by a locomotive crane.

Stone and screenings were generally delivered to the mixer hoppers by a locomotive crane using a clam-shell bucket so that hand labor in delivering materials to or from the mixers was but little used.

Discussion.

President Chamberlain: The paper of this evening has to do with, probably, one of the most important features of an engineer's or a contractor's work. There is in it a great deal which is instructive and of value to any one who is engaged in any way in structural work of the classes mentioned in the paper. The old-time contractor obtained his prices largely, I think, by guesswork. I have talked to contractors on railroad work and they would say, "Well, I can do such and such a piece of work; I can take out that cut for 32c a yard," apparently guessing or jumping at the price from their former experience; that is, they made no analysis of how they obtained that figure. In the present days of close competition and scientific figuring of costs of work, such methods are, I think, extremely dangerous to a contractor or an engineer. We would hardly expect an engineer to take that method of arriving at the result in any case. A good many contracts are secured—I think a very fair minority of the contracts—by omitting some item in the cost in figuring the work. I know of a dozen cases where contracts have been secured in that way, and recently a contract involving about $80,000 worth of work was secured by the contractor omitting one item of his costs. He did not discover the omission until the day after the letting of the contract. A number of years ago I knew a man who afterward became one of the most prominent bridge constructors in the East. He told me that he secured his first contract for a highway bridge when he started in business (having previously been employed by another concern) by forgetting, in making his calculations, to insert one truss of the two trusses of the bridge. The proposals called for a lump bid and he figured up his lateral bracing for one truss, took his weights for that, forgot to double the truss, and secured the contract. It was an unfortunate start for the new firm. Of course, these things are avoidable by proper care.

Recently a contractor on a small job asked me to figure the amount of stone and cement necessary to do the work. I happened to know what price he had on the work. I did the figuring, which was rather insignificant, and said, "How did you figure the job in the first place?" (I thought a man who was unable to figure the amount of material was hardly competent to figure the job.) He said, "So-and-so bid on such-and-such a job similar to this, such-and-such a price, and I thought if he could do it for that, I could do it for 2c a yard less." That was going back to the old-time methods of the old-time contractors.

Mr. Windett's paper presents a careful analysis of costs, as well as values and methods for keeping costs, on work in progress to be used in calculating similar work.

One feature of the paper impressed me very favorably, and that is the care with which the rates of labor have been given throughout in estimating these costs. As Mr. Windett says in the early part of his paper, he has done that so that the paper can be used regardless of what rate of labor is being considered. In tables of calculation of cost it is absolutely necessary that the rate scale should be shown to make them of any value whatever, on account of the difference in scale of wages in different parts of the country and even different localities in the immediate vicinity. For instance, in Chicago the labor rates on sewer work are probably materially different from those within a radius of fifty miles of Chicago, on account of the labor conditions, the union scale, etc. The rate on which these calculations are made being given, makes it easy for an engineer to adapt the table to the prevailing rates at whatever point he expects to work.

C. C. Saner, ASSOC. W. S. E.: Referring to the average hourly cost, under the caption "Method of Cost Keeping," I would ask Mr. Windett if an account was kept of the amount of work done per man at these different rates? That is, I should think, even if the hourly rate be raised, if more men were worked in proportion, the overhead cost would be cut down that much.

Mr. Windett: Yes, the amount of work done each day, its cost, and the number of hours labor per unit of work was carefully watched.

F. E. Davidson, M. W. S. E.: The figures given for the cost do not contain one very important item of cost and that is the overhead charges, which any general contractor or any contractor must pay. That is, the cost of general superintendence, office expense, and all that sort of thing. I would ask Mr. Windett about what the overhead charges would be, on work of this kind. I have reference to such items as accident insurance and general contractors' overhead charges.

Mr. Windett: In general the costs given are those of the "field costs." The "overhead" or office expense is an item the magnitude of which is not definitely proportioned to the cost of any particular work under consideration. The amount of office expense, in part, is dependent rather upon extraneous conditions not governed by the field work. For instance, an expensive organization may be maintained through comparatively long periods of slack work, and again a certain office force can and has handled several large contracts simultaneously. Office expense has been given in some instances in the paper, and where given it is so stated. There are a number of contractors whose office expenses are of a most insignificant kind, having no office force, while competitors maintain a permanent and large office organization, whose overhead charges reach 18% to 20% at times. The writer knows of one Chicago firm whose work last year averaged seventy-six jobs per month, some of which ran into several hundred thousand dollars each. Their office charge would be a much smaller percentage than that of a contractor having but four or five moderate pieces of work.

President Chamberlain: In connection with the question Mr. Davidson has brought up, it might be said that this matter of overhead charge is a very indefinite one. I think that he will agree with me that one constructing engineer or contractor will prorate his office expense over his contracts, where another will omit from the overhead to consider all general expense and simply figure a flat rate to cover it. The whole term to me is very misleading. A line must be drawn somewhere by each contractor or representative of each firm who is managing the business, at which he will say everything below this line shall be charged out to the contract—that is, every employee below a certain scale. In some cases I know the line is drawn at the outside superintendents. The entire office charge is part of the overhead. Another contractor or engineer might prorate his office expenses through the different contracts. So, when we come to talk about overhead expense, we are getting into something, I think, that is very indefinite.

Mr. Davidson: There is another item of expense that has not been mentioned, and that is the depreciation on the contractor's plant. How much are we going to depreciate it for the different jobs or the plant per year, or how are we going to figure that?

Mr. Windett: As to depreciation of the plant. For one contract I bought two concrete mixers of the same make, size, and price. At the close of the work, lasting a year, the depreciation measured by the sale of the machines amounted to $25.00 and $100.00. The depreciation and wear and tear are uncertain variables, as unsusceptible of expression as a fixed percentage as is the item of "office expense." One common method of figuring depreciation is to charge direct to a job the entire cost of small tools, special tools applicable to the work in question, and certain assumed fractions of the cost of tools which are of general use, such as pile-drivers, concrete mixers, steam shovels, etc.

President Chamberlain: If I understand you, Mr. Windett, I think these tables deal entirely with the outside expense. It is practically from the superintendent of the work outside down?

Mr. Windett: It is all outside expense.

President Chamberlain: That would be my interpretation of it from looking over the tables.

L. K. Sherman, M. W. S. E.: I would ask Mr. Windett if he has given any consideration or made any study as to the relative economy of brick or concrete sewers, and, if so, whereabouts he would draw the line? What are the conditions that make a concrete sewer economical in one place and a brick sewer economical elsewhere?

Mr. Windett: As to the relative cost of brick and concrete sewers, Table II shows a comparison in cost per lineal foot. The diagram given with the table shows a wide difference in cost with a tendency of concrete to approach brick costs as the size of sewers increases.

As to the relative value of the two materials, brick is preferable in wet trenches. In fact, in such a trench concrete cannot be used unless the sewer is made in sections on the ground surface and lowered into place when set hard.

Regarding the relative economy based on durability, it is difficult to find a material for sewer construction superior to a sound, dense, hard-burned brick laid in a rich cement mortar. The writer has seen, in many sewers of concrete during the "acceptance inspection" before the sewer has been put into service, many evidences, such as the formation of small stalactites, of the dissolving of the cement in the concrete by action of ground waters.

BALL BEARINGS FOR HEAVY LOADS.

H. Gansslen, assoc.w.s.e.

Presented September 13, 1911.

As presented to the practicing engineer, the problem of friction in bearings is one connected principally with the question of economy in the operation of machinery. It is a problem, however, that has a broader meaning as well. Reduction in friction brings about saving in fuel. The conservation of our fuel resources is an important part of the movement toward the conservation of all natural resources, that is attracting so much attention from the government and the people.

The economies being obtained by the generation of power in central stations have already eliminated in Chicago alone, hundreds, if not thousands, of small individual power plants. This, while unfortunate in that it works hardships on the small producer, is undoubtedly a development along logical lines, and is sure to result ultimately in benefit to the people as a whole.

But, in the most economical steam power plant, there is only about 12% of the energy of the coal made available for driving machinery. Out of this amount from 15% to 60% is lost by friction in transmitting the power from the engine to the individual machines and tools of the plant. Furthermore, there are friction losses in the various machine tools, the magnitude of which is often unknown to the designer; in fact, in many cases these losses are not even considered, as we have grown to look upon them as a necessary evil. The element of machine design which is the most important factor in the way of power losses by friction, is that of shaft bearings.

The writer has spent considerable time in engineering testing and research work connected with bearing friction and desires to present to the Society some of the results of this work. The subject matter of this paper is largely the result of tests made by the writer under the direction of Prof. Stribeck, at the engineering laboratory of Neu-Babelsberg, near Berlin. This laboratory, erected about 14 years ago by an association of German manufacturers, was designed to provide a central institution where engineering investigations having a commercial end in view could be conducted thoroughly and economically. The writer is indebted to Mr. Henry Hess, of the Hess-Bright Manufacturing Co., for some of the illustrations and for a portion of the information given in this paper.

As early as the time of Aristotle some thought was being given to the question of friction in bearings. In his work entitled *Mechanical Problems* Aristotle treats this question in discussing rollers and wagon wheels. In the writings of Leonardo da Vinci it is shown that the angle and coefficient of friction are independent of the size of the sliding surfaces. Various later writers have treated this question, but there has been much difference of opinion on important points, and many contradictory statements have been made; and only in recent years has it been possible to establish principles and methods of an authoritative nature, based on scientific deduction.

About 14 years ago the German Small Arms Co. began manufacturing steel balls, and at the same time tried to increase the demand for them, especially for the larger sizes. The outcome was an attempt to build ball bearings for any desired load. At that time no theory of design existed other than certain empirical rules derived from experience in the manufacture of ball bearings for bicycles. This firm turned the matter over to the above named laboratory for investigation. These investigations, extending over several years, were made and general principles were established. This work resulted almost immediately in the adoption of the ball bearing for automobiles, and for other engineering purposes. Tests were made at the same time on representative types of roller and plain bearings with a view to determining their friction at different loads and speeds, their permissible loads, and other features and merits.

THE BALL BEARING.

Prior to this time there was no engineering basis for designing ball bearings, except a few formulas on the *Contact of Elastic Bodies* by Hertz, and other formulas by Auerbach. These, in some respects, contradicted each other. Manufacturers of steel balls stated that the permissible load on a ball in a bearing was 9940 d^2 lb. where d was the diameter of the ball in inches. They arrived at this figure by breaking a ball between two hardened steel plates in a testing machine and taking one-eighth of the breaking load as being the permissible load. Today, it is known that the permissible load on a ball in a bearing is about one-fourth or less, of the one then given. This fact accounts for many failures in the past. We know further that the breaking load of a ball cannot give any information as to the permissible load in service and that to arrive at the latter we must consider the occurrences at the places of contact between the balls and ball races, or balls and plates. See Fig. 1.

After several years of investigation the following principle was established: *In hardened steel balls under pressure the average stress* p, *Fig. 2, as well as the maximum stress* p_0, *in the flat surface of contact, is equal for balls of any size if the loads are proportional to the square of the diameter,* d, *of the balls;* or, to formulate, $p=kd^2$, where k is a coefficient determined by the kind of material used and the shape of the supporting surface, whether plane or curved.

The balls used for the early tests reached their elastic limit with a load of 71 d^2 lb. After passing that load, the sets appeared very slowly, so that at a load of 568 d^2 lb. the set was only about 1/50 of the elastic compression. If a hollow support is used having a radius of 2/3 *d*, in place of the flat plate, the load sustained is about 3½ times that of the previous case.

The material used for the balls and races was, aside from the

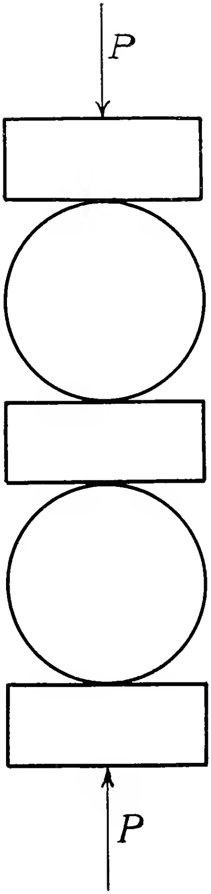


FIG. 1.

design of the bearing, the most important factor in the matter of success or failure.

TESTS.

The regular tests of the material comprise the hardness, toughness, and fracture tests, the latter being mainly for the purpose of getting information of the structure or grain of the material. Later on, a vibration test was added, and all these tests were checked, so to speak, by a running test of the complete bearing at different loads and speeds; this not only furnished frictional data, but often was severe enough to cause destruction of the bearing.

HARDNESS.

If two balls of the same material are pressed together with a load P, there is formed a circular plane surface of contact of radius

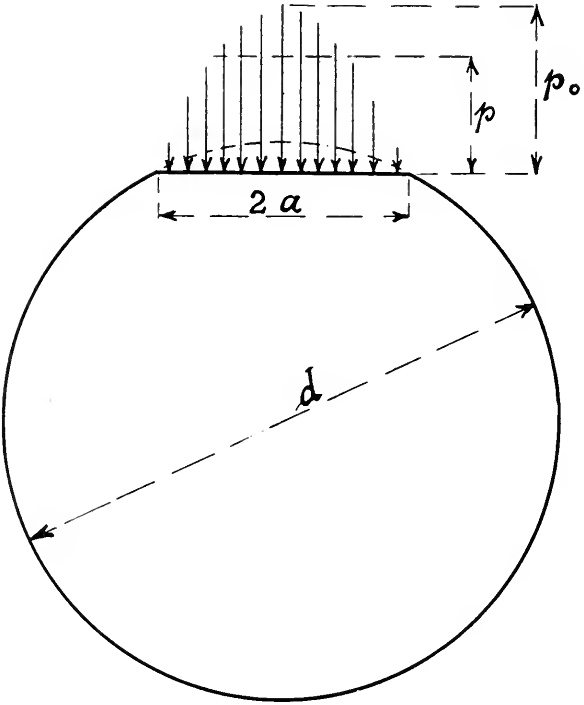


FIG. 2

a. The area of this surface increases at first with increasing load at the ratio of $\sqrt[3]{P^2}$, and the average stress $p = \frac{P}{\pi a^2}$ increases at the ratio $\sqrt[3]{P}$. Shortly after passing the limit of proportionality of the material, the area of contact grows faster and the stresses slower than at first, until finally a point is reached where the area πa^2 increases in the same ratio as the load, and where, consequently, the stress remains constant up to the breaking point of the ball. This stress, which indeed is a very noteworthy point, is called the hardness of the ball.* Good balls of any size have a hardness of from 1,107,000 lb. to 1,206,000 lb. per sq. in. Small balls have usually the greater and large balls the lesser hardness. Balls that are not thoroughly hardened clear through, but have a hard outer shell only, show a decrease of hardness after the latter has reached a maximum, as indicated in the diagram, Fig. 4.

TOUGHNESS.

If the load on two balls is gradually increased, a stage is reached where fine local cracks become visible at or near the circumference of the circle of contact. The first of these cracks follows that circumference exactly, and at its very inception is visible only under the microscope and after the surface of the ball has been treated with an acid. This load is still far below the breaking load. The larger the load and the compression at the moment when this first surface crack appears, the tougher is the ball. Toughness is defined as the mechanical work necessary, per unit of the cubic contents of the ball, to compress the ball between two other balls of the same size up to the point where the first surface crack appears. Good balls must have a toughness of not less than 3.56 ft. lb. per cu. in., which corresponds to a load of about 6675 d^2 lb. (d in ins.). This refers to balls of any size. Exceptionally good ones have a toughness of as much as 11.86 ft. lb. per cu. in.

BREAKING TEST.

This test is made to get the breaking load and especially to get fresh and clean surfaces to show the grain or structure of the material. From the appearance of the surface in case of hardened steel, important conclusions are drawn: it shows whether the ball was overheated in forging, annealing or hardening; whether it is hard clear through, as is to be expected of a good ball, or whether it has only a hardened shell; and in the latter case, whether the hardness diminishes gradually or suddenly toward the center. The ball under test is usually put in the testing machine between two other balls, as it then splits along a plane through the center. The load at the breaking point is of no importance, as there is no relationship between that load and the admissible load on a ball in a bearing. The latter is better determined by the previously described tests. Two extreme cases show this lack of relationship; a ⅞ in. ball showed the first crack at 7820 d^2 lb. and broke at 113,500 d^2 lb.; a 1¼ in. ball showed the first crack at 14,200 d^2 lb. and broke at 49,700 d^2 lb.

SUNDRY TESTS.

Recently there has come into use a bending, or rather a vibration test of the material entering into the manufacture of ball

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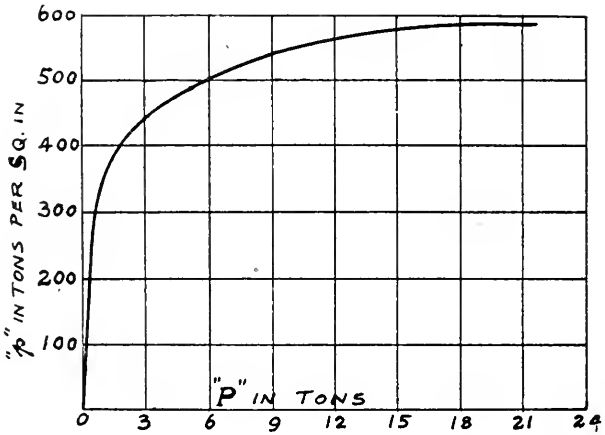
*Illustrated in Fig. 3.

bearings. A piece of rod of the material to be tested is subjected to a series of rapid light blows, and the number of blows given before certain defects appear on the surface gives a criterion as to the suitability of the material. A convenient means of testing the hardness of a ball race without having to waste it, is the *scleroscope.* A minute weight with a diamond point is dropped from a certain height on to the object to be tested, and from the rebound comparative conclusions are drawn as to fitness of the material for the purpose in view. Of two ball races of the same hardness (as tested by the use of a file), one will show a smaller rebound than the other, which may have been burned and was thereby rendered useless, or at least inferior in quality.



HARDNESS OF WELL HARDENED 1" BALLS.

FIG. 3

THE BEARING.

We now turn to the bearing itself; in Fig. 5 are shown a number of types that were tested. These are of the 2, 3 and 4 point contact type. The first one was adopted as the standard of the radial bearing on account of its lowest possible coefficient of friction combined with its relatively highest admissible load. All the other types are of the built-up type and are therefore provided with an adjustment; thus making them possible or even probable of destruction by inexperienced attendants.

The fewer the balls used, or in other words, the larger the diameter of the balls, the less will be the friction in the bearing.

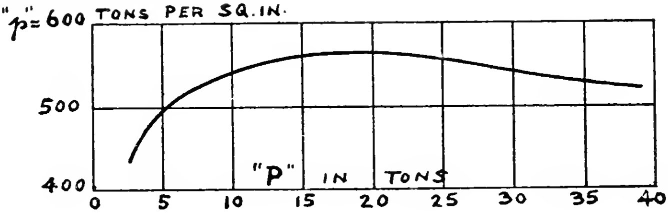
In the standard bearing, from 6 to 20 balls are generally used. Referring to that case we have Fig. 6:

$p_0 z = 5P$ for the whole bearing unit, and

$p_0 = kd^2$ for the maximum load on any one ball.

P is the total load on the bearing, and z is the number of balls; k is a coefficient explained above.

From these two equations the following equation for the design of the standard bearing is derived: $P = kd^2 \frac{z}{5}$. Where P is given in lb. and d in units of ⅛ in., and the radius of curvature of the race is 2/3 d, then $k = 33$ for those alloy steels that have proved most satisfactory for the purpose. The constant 5 was deduced mathematically. More accurately it should be given as 4.37, assuming that there is no play between the balls and races, and that the latter cannot get out of shape when under load. In using this constant it might appear as though 1/5 of all the balls participated equally in carrying the load. In reality, of course, only the one ball directly in line with the direction of the load has to carry the maximum load p_0.



HARDNESS OF POORLY HARDENED $\frac{7}{8}$" BALLS

FIG. 4.

In Fig. 7 is shown a friction test diagram of the standard radial bearing, giving the relation between load and coefficient of friction. The latter is practically constant for widely varying loads, so that at 1/10 of the rated load the coefficient of friction increases only from 0.0015 to 0.0030. This coefficient refers to the diameter of the shaft so as to make it directly comparable to the one given in the same figure for plain bearings. The shaft diameter used for all tests was 2¾ in. Any ball bearing which under its rated load has a coefficient materially larger than 0.0015 is inadmissible because it has an undue amount of sliding friction and its life will consequently be short. There is no change in the coefficient of friction owing to speed; and the kind of lubricant, whether thin or heavy, is also without effect. This, however, does not mean that the bearing can run successfully without oil, or with oil containing acids often found in certain lubricants; such conditions are disastrous to the bearing. The friction testing machine or scale on which the tests were made, is shown in Fig. 8.

The radial bearing, Fig. 9, can also be used in places where there are moderate axial or thrust loads not exceeding 1/3 of the radial load; as the races are uninterrupted, the balls being inserted to fill only part of the annular space; the clearances are then filled by distance pieces which also act as oil carriers. For larger thrust loads it is necessary to use a regular thrust bearing as shown in Fig. 10. Without going into details, it may be said that the admissible load of this bearing decreases with increasing speed. This fact would indicate that there is a certain amount of sliding friction prevailing, owing to centrifugal action, in contradistinction to the standard radial bearing. The distribution of the load over all the balls is of the greatest importance, and the illustration shows the means employed to that end. The successful ball bearing must comply with the following requirements:

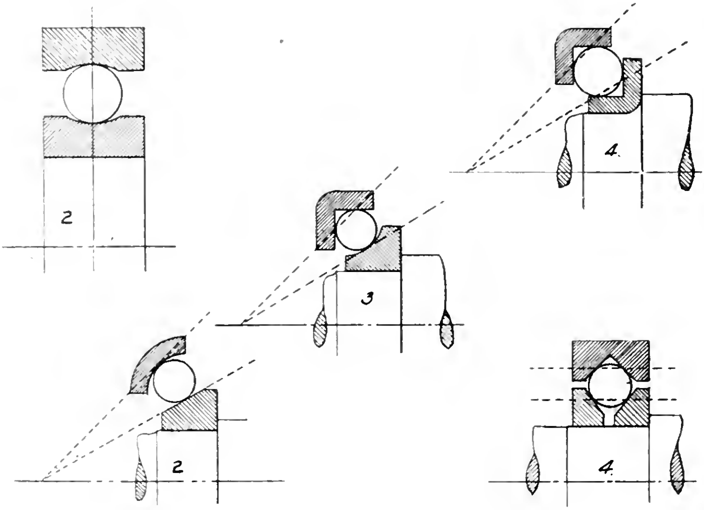


FIG. 5

Different Forms of Ball Bearings.

Design: The carrying surfaces of the races should be at right angles to the load direction and be curved with a radius somewhat greater than ½ *d* to get the maximum carrying capacity. The races should be uninterrupted; that is filler openings for the balls should be omitted.

Material: Material must be uniform in hardness and toughness not only as to the different parts of a bearing, but also as to the particles of each individual part. The elastic limit, hardness, and toughness must be high to the best obtainable degree.

Workmanship: The running surfaces must be true as to shape and size. The balls in one and the same bearing must not vary in diameter more than 0.0001 in., both individually and collectively. The running surfaces must be ground perfectly, and when examined under a microscope of low power there must be no scratches visible. Ball bearing and ball making machinery have been perfected to such a degree that the radial clearance of an assembled radial bearing is less than 0.0001 in., and the axial clearance ranges from 0.006 in. to 0.0006 in. according to the size of the bearing. Ordinary commercial balls, as a rule, do not fulfill these exacting requirements, and no one but a specialist can make a ball bearing comply with them and guarantee results. Their manufacture requires the closest supervision and the price cannot be expected to be as low as that of a plain bearing. Engineers, of course, have to look to the question of cost.

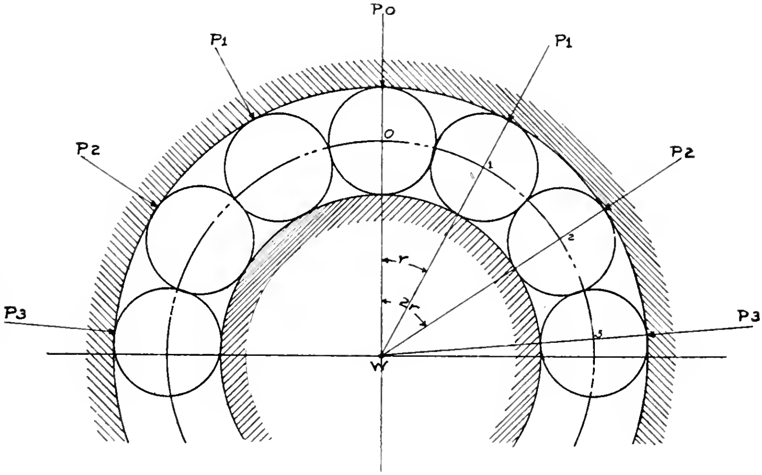


FIG. 6

Typical Ball Bearing.

Recent shop practice has demonstrated the commercial outcome of the above theories and tests by the adoption of ball bearings under almost all conditions of loads and speeds. The earliest and most important use was on automobiles, where power economy is an all important factor. Hundreds of thousands of ball bearings have been used for this purpose, as in the actual construction of grinding machinery, cranes, mine hoists, paper machinery, gun carriages, electrical machinery, marine appliances, line shafts, etc.

It is a well demonstrated fact that in the average manufacturing plant there is wasted in the line and counter shaft bearings from 20% to 60% of all the power consumed. A few years ago the author was called upon to investigate the advisability of using ball bearings in place of the ordinary plain bearings for the line and counter shafting in a new can making plant, where about 135 hangers for $1\frac{15}{16}$ in. and $2\frac{3}{16}$ in. shafts were to be used. The excess cost of ball bearings over plain hangers was several hundred dollars. It was estimated that it would take about five years to make the calculated power saving pay for the excess in first cost. It was decided not to incur this expense, especially since power cost was a small item in the total cost of production. The assumptions as to the loads on the bearings were weak, because they were based on the friction of individual bearings as tested in the laboratory. In the meantime more accurate tests were made as to the total friction on line shafts (see Transactions A. S. M. E., 1908). These tests show that the actual line shaft friction is very much larger than was figured on in the above case and that the saving, therefore, as estimated was too small. Furthermore, the ball bearing today is lower priced than at that time and in the average case now it is a well paying

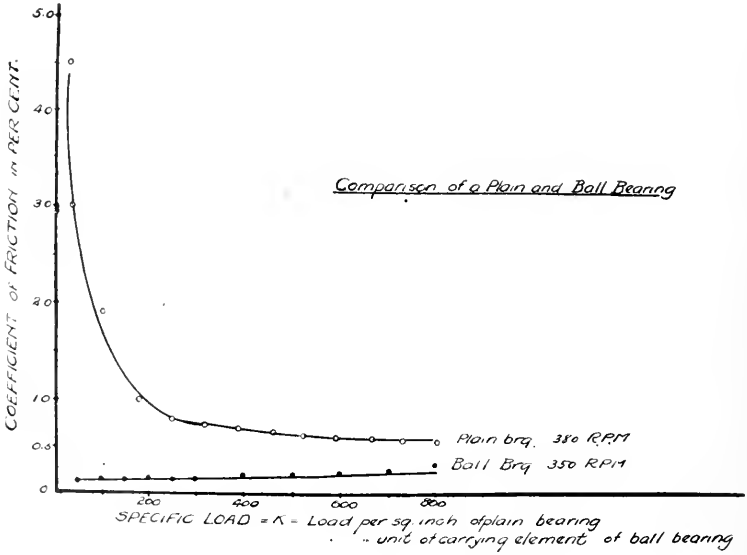


Fig. 7. Friction Test Diagram.

proposition. The results of the tests point to a saving of 37% annually as a return on the extra investment. In view of the fact that ball-bearing line shafts can be run at higher speeds than plain ones without danger of overheating, it is even possible, under certain local conditions, to get the first cost of the total equipment as low as with plain bearings, or lower. This is partly due to the use of smaller belts, pulleys, shafts, etc., incidental to the higher speed. On account of the low friction there is no overheating possible, and line shafts in flour, saw, cotton, powder, and other mills should be equipped with ball bearings because of the lessened danger from fire and lower insurance rates.

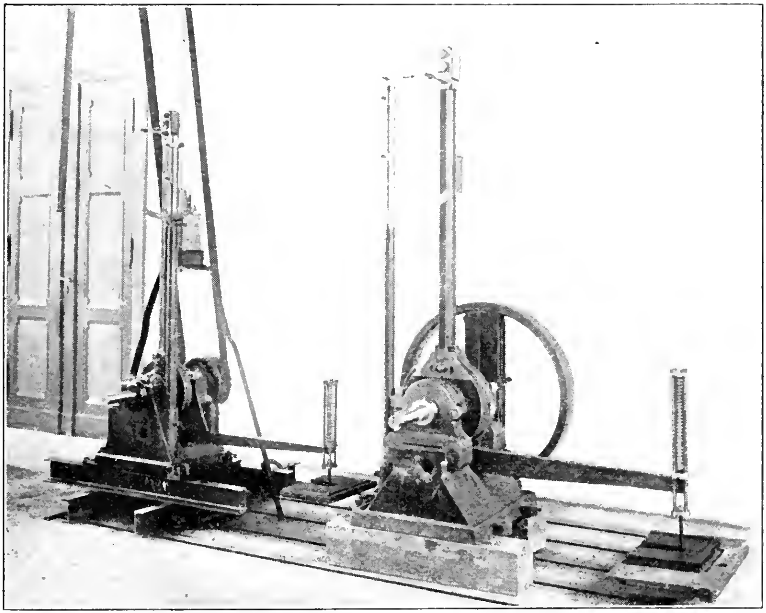


Fig. 8. Friction Testing Machines.

PLAIN BEARINGS.

In Fig. 7 is shown two curves referring to tests with plain and ball bearings. In a similar manner as they demonstrate graphically the dependence of the coefficient of friction upon the specific load, it has also been proved that the speed, the temperature, the lubricant, and the occurrences during the dangerous period of the running-in are all affecting the coefficient of friction in a large measure. Under the best obtainable conditions of load, speed, etc., during such a laboratory test, the coefficient of friction is not vastly different from that of the roller and ball bearing, but such conditions do not prevail in practice. The friction of repose, also at starting and slow speeds, is especially high on the plain bearing, and for these conditions the saving of the ball bearing is particularly apparent.

ROLLER BEARINGS.

Theoretically this bearing should have the same low friction as the ball bearing; but the theoretical requirements set forth above cannot be met. The materials and workmanship, as well as the accuracy of the present commercial roller bearing, are far below the requirements, and consequently the coefficient of friction is larger than that of ball bearings, as indicated in the diagram, Fig. 11. In relation to load and speed, this diagram shows points of similarity to the plain bearing diagrams already shown. On account of the relatively soft materials that it has been found practicable to use, this bearing is principally used for light loads. This sounds rather strange in view of the common reasoning of the mechanic as to the larger line contact of a roller over the point contact of a

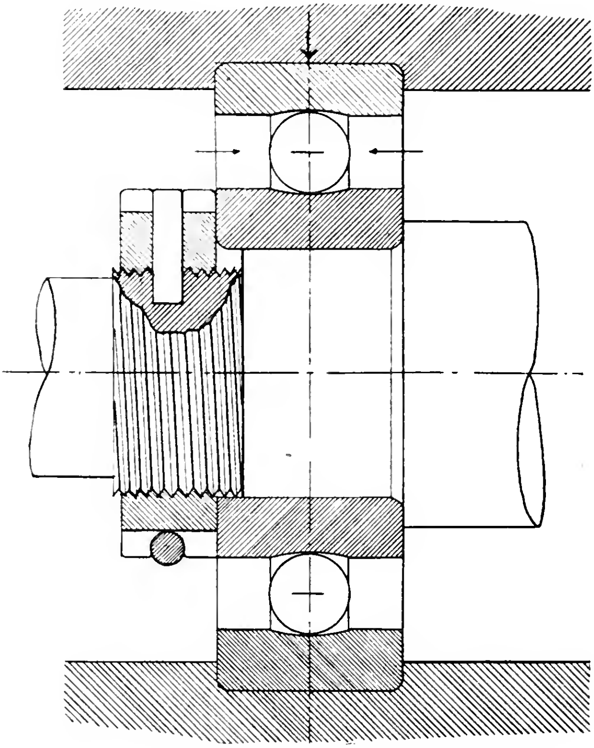


Fig. 9. Combined Radial and Thrust Ball Bearing.

ball. The roller bearing is proportioned in a manner analogous to the ball bearing; the formula used is $P = \frac{k\,l\,d\,z}{5}$. l being the length of the roller, and the other symbols having the same meaning as in the ball bearing formula. The coefficient, k, must be small, as the rollers are relatively soft. For this reason the bearing is practically as long as an ordinary plain bearing of the same capacity. On the other hand, the ball bearing is no wider than the hanger itself, thus making available valuable space for pulleys on line shafting for instance.

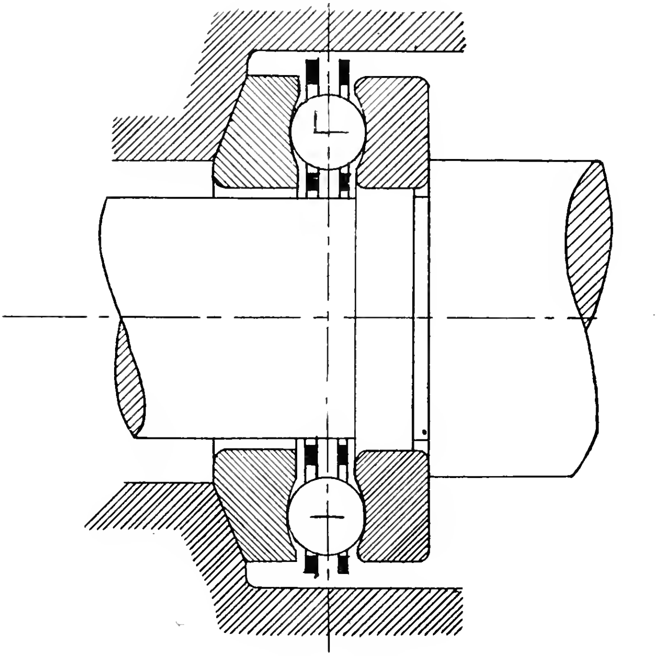


FIG. 10

Thrust Bearing.

IN CONCLUSION.

It would appear that today there are very few conditions under which the ball bearing cannot be used successfully, assuming that the requirements and conditions are clearly understood by the maker, and that the bearings are properly mounted. The troubles incidental to the running-in of the plain bearing are avoided; the friction is as low the first day as it will be after years, and there is no wear. Any visible wear means destruction.

The item of saving power is in most cases so important as to pay for the bearing in a reasonable time, 90% of the friction of plain bearing being often saved by the ball bearing. Ball bearings require very little space on the shaft for any speed or load as compared with plain or roller bearings. As the ball bearing does not heat there is no fire danger due to hot boxes.

There were many failures in the early stages of development. Most of them were due to the fact that there was little or nothing in the way of scientific basis for design. Some failures occurred when mechanics tried to make ball bearings for their own use without the necessary knowledge or appliances. Failures have been

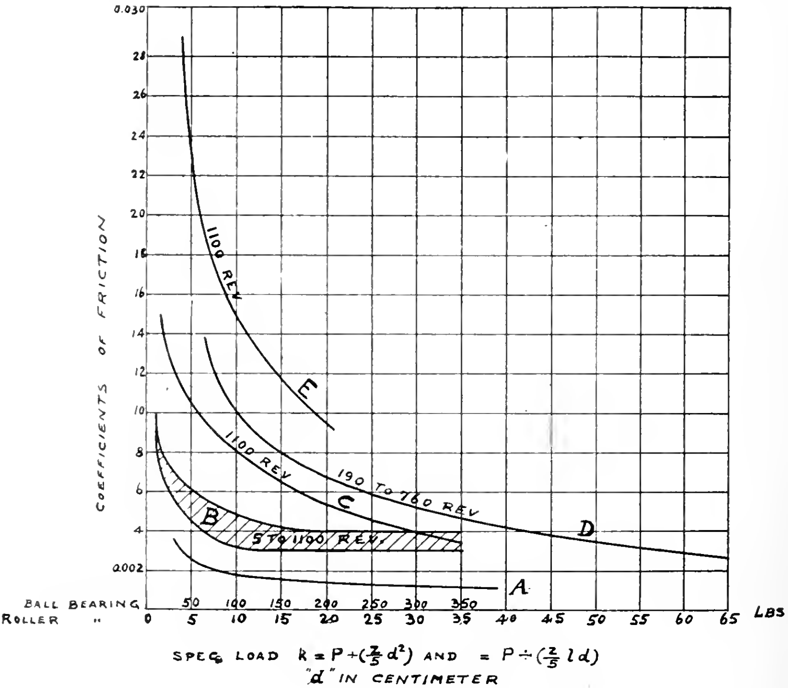


FIG. 11

Friction Diagrams.

A. Ball Bearing with 14 Balls.
B. Hyatt Roller Bearing.
C. Kynoch Roller Bearing.
D. Roller Bearing, Hollow Cylinders on Pins.
E. Mossberg and Granville Roller Bearing.

caused by insufficient allowance for belt pull. The bearing would seem to be sufficient if figured on the customary basis of 40 lb. to 60 lb. of belt pull per inch of belt width; but experience has shown that belts are often made too tight, and the present practice is to figure on 350 lb. per inch of belt width.

The theoretical basis for the design of ball bearings is now well established; but the exacting requirements confine the manufacture to a few specializing firms. Standard radial bearings are made in units up to 15,000 lb., and thrust bearings, for slow speeds, as high as 300,000 lb. load. Special bearings for practically any load are feasible.

DISCUSSION.

Ernest McCullough, M. W. S. E. (Chairman): There seems to be, among engineers, several subjects on which discussions can be worked up on short notice and made rather interesting. Civil engineers delight in the subject of earth pressure, and mechanical engineers develop quite a little heat in discussing the production of steam and the question of the utilization of the energy in machines. Since this paper was printed I have heard several engineers talking about the subject of friction and anti-friction bearings, and was greatly interested in the divers views presented. We hope tonight to bring out considerable discussion which will be a real addition to the literature of the subject.

W. E. Symons, M. W. S. E.: The paper is an interesting one and will be quite a valuable addition to literature on the subject. There are one or two points, however, on which I would ask the author if he will not kindly give us a little information in his closure,—namely, with respect to the kind of material of which the balls are made and a chemical analysis. I judge, of course, from the lantern slide views we have seen since the paper was read, that they are made of steel, and, I assume, crucible steel, although, I am not sure of that. It has occurred to me, inasmuch as this paper is so largely devoted to the design or the theoretic features of ball and roller bearings, that the kind of material of which they should be made, in order to secure the best results, and its chemical composition, would be not only interesting but proper data to accompany the paper. If this were done, in referring to the paper as authority with respect to the design, construction, manufacture, or operation of ball or roller bearings, there would be a complete index to any phase of the subject on which it might be desirable or necessary to secure information.

The practical use of ball bearings is, of course, largely in the experimental stage in railway operation, and I assume that there is not much information from that source. Their use so far, on stationary machinery, has been productive of good results, and the experience thus gained, not only from their economical operation but with reference to the design of the bearings, is such as to encourage their extended use in other directions.

The advocates of ball or roller bearings have already slightly invaded the transportation or railway field, with their devices, and have demonstrated their superiority from a purely theoretic standpoint, in that where ball or roller bearings are applied to car trucks, the amount of force or power necessary to move the trucks is reduced to a great extent. The movement of a truck from standing position, can be accomplished with the pressure or strength of one finger, as against the use of a crowbar or the entire strength of an adult man, with a truck fitted with ordinary brass and friction journal bearing. These theoretic tests in some instances, I think, have led the advocates of their use on railways, to *over-estimate* the probable economies that would come from their general use in train operation, and to *under-estimate* the probable cost of their maintenance; this for two reasons:

First. Those who design and advocate the use of ball or roller bearings are associated with the proposition largely in laboratory or experimental tests, and have not come in contact with the practical question of its care and maintenance after being placed in general use, and turned over to an entirely different class of people to handle, than those who either design the device or conduct the laboratory tests.

Second. The economy to be effected in railway service has been *over-estimated* to the point of a wild guess, for the reason that the estimates have been predicated or based upon the relative friction, as shown by laboratory trial tests of the two types of bearings, which are not only misleading, but rather deceptive. When considered wholly from the standpoint of the relative friction per truck on car, this would and undoubtedly has led some of those who advocate the use of ball or roller bearings on steam railway trains to a fallacious or erroneous conclusion. This is because the amount of fuel necessary to propel railway locomotives and trains, no matter whether steam or electric, particularly at the higher speeds, is largely in overcoming atmospheric resistance. At extremely high speeds the amount used to overcome journal friction is so insignificantly small in comparison with atmospheric resistance that one could hardly find it by mathematical calculation. So the amount of fuel that would be saved in the movement of railway trains of high speed would be so very small an item that it would not justify the expense of changing. Again, if the claims of some who urge their use on freight trains were fully realized, then the railway companies would find it necessary to materially enlarge or lengthen their yards and side tracks; it has been claimed that the trains it is possible to haul when provided with ball or roller bearings would be so long that there are few, if any, side tracks long enough to hold them.

There are a number of interesting points in connection with this matter that doubtless can be reviewed by those who have had more experience with the bearings than myself. I shall be very glad indeed if the author will give us a little information in his closure with reference to the kind of material used in the manufacture of these bearings and its chemical composition.

Eugene A. Balsley, ASSO. W. S. E.: Several years ago two gentlemen, one of whom is here tonight, took out a patent on a roller-bearing or ball-bearing turntable—an engine turntable. One turntable was built which could be moved with the point of a lead pencil with the full weight—65 tons per engine turntable, I believe was the weight of it. They thought they had a wonderful thing, but after a few months the balls began to wear and they could not find any good reason for it. I would like to have Mr. Gansslen tell us why there should have been that trouble. Of course, it was a thrust bearing, but the balls undoubtedly were not moving in a straight line on account of the inversion of the bearing.

Mr. McCullough: It looks as if they had something of the sort as an equalizer in that gun mounting.

Mr. Gansslen: Undoubtedly the reason for that failure is one of two—faulty material or faulty design. The designer evidently did not know the admissible load on the balls, or else the conditions under which the bearing was used were such as to cause its destruction. Without knowing the design or the conditions, it would be difficult to explain the cause of the trouble.

Mr. Balsley: I will show you the picture of the drawing of the bearing. Perhaps you can get a better idea of it.

Mr. Gansslen: In this case no equalizer was used, so no one could be certain that the entire load was not taken up by just one or a few balls, as far as I can see here. A thrust bearing for these conditions, designed on this principle, I presume would mean failure. It is nothing but two straight disks, the upper one being hollowed out slightly, the lower one straight.

Mr. McCullough: Now that you see the patent papers, are you familiar with the bearing?

Mr. Gansslen: No, I am not. This is patent 455,009 to C. Weatherson and P. K. Richter, taken out in 1891. At that time there was no one who knew anything about proportioning a ball bearing properly, either the thrust or journal bearing. No one knew anything about the material that should be used, the size of the balls, or anything of that kind, so I do not wonder that it was a failure. The year 1891 was before the author or any one else had made extensive tests. There was no theory available then for proportioning ball bearings, except some mathematical results of a few men, as mentioned in the paper.

Mr. McCullough: Early in the 90's I was employed as a designer on mining machinery, in an engineering works in California. We were asked to make a patent arastra—a sort of circular mill for grinding ores. Ball bearings were put in, but the conditions in use were not satisfactory. I think the specifications required that the balls were to be as hard as possible. The machine was sent into the wilds of Mexico, and in about a month trouble with it was reported, and finally a Mexican took out all the balls and put in sections of pipe for roller bearings.

Mr. Balsley: I would ask Mr. Gansslen if it would be feasible to design a 200-ton engine turntable with ball bearings, where part of the time the engine is on the center of the table and part of the time it is not, and the load is varying from one side to the other, according as the engine is run on the table.

Mr. Gansslen: There is little that is impossible in the way of designing a ball bearing for most any load, as long as we understand the principle on which to base the design and know the requirements. Without going into the matter in detail, I would not want to commit myself. We have heard what ball bearings have actually been used for in the past, with success, and probably in the future we will go further; that is, subject the bearings to still greater loads.

Mr. McCullough: Mr. Gansslen shows some very high values to prove the superiority of the ball bearing over the plain bearing, and we all know, from what little knowledge we possess of the automobile, that the ball bearing is a very good thing. Whether it can be applied as universally as the advocates claim is something that we are all going to have an opportunity to find out in the next few years.

There is an excellent opportunity for the introduction of these improved bearings, not alone in the automobile or bicycle but in every machine that is used.

W. L. Batt (Hess-Bright Mfg. Co.): When I heard that Mr. Gansslen was going to give a paper on the subject of ball bearings for heavy duties, it occurred to me that probably some information from a commercial view-point might be of interest to you, because Mr. Gansslen is forced to look at the subject largely from a technical view-point, inasmuch as he is not commercially interested in the application of ball bearings, while we, as a company, are; we have at hand information which would not be available to any other person or to any other body of engineers.

One of the first things that the inventive mind of man began to work with in the early days was to substitute rolling friction for sliding friction. That is probably first exemplified in the substitution of a wheel for a sled. If the rolling action of a wheel did not make a vehicle easier to propel, doubtless we would still be on the original method of propulsion—that is, pulling some sort of a sliding vehicle along on the ground. If you take your hand and slide it on the desk, and then, put a pencil under it, you get a rough approximation of the difference between rolling and sliding frictions.

As Mr. Gansslen has pointed out, the development of the ball bearing in the earlier days was greatly handicapped by insufficient knowledge, and it is only within the last ten years that any sort of an opinion could be predicated as to the results which may be obtained with the anti-friction bearing; in that case I make the term anti-friction bearing to cover both the roller and the ball bearing. While the company with which I am connected is primarily interested in ball bearings, yet the whole subject of anti-friction bearings is one with which we have to deal.

If a ball bearing were properly constructed as to theoretical considerations, and yet had improper materials, we should have failure; or, if we had the best materials at hand but a poor design, we should have failure; or, finally, assuming that we had the best bearing to be had and an imperfect knowledge of the conditions under which that bearing was to operate, we should, again, probably have failure. In other words, we can readily see that in the application of ball bearings, just as in the application of mechanism of any kind, we first have to have the correct mechanism and then a correct knowledge of the application of it.

We many times receive requests for a ball bearing or an anti-friction bearing for a 1½ in. shaft, and that, to the average man's mind, covers the whole proposition; but he has not given us an idea of the entire condition in that statement. If I ask you to put a plain bearing on a 1½ in. shaft, the question will be just as logical. Plain bearings are of all dimensions, of all compositions, and of all designs, and ball bearings offer probably even a wider range of opportunity for selection.

The first speaker in the discussion asked Mr. Gansslen to discuss the subject of materials, and I will leave that for him, only mentioning that the ball bearing for heavy duty should be made of the very finest materials to be obtained. The old bicycle ball bearing, with which probably a good many of us are familiar—maybe from sad experience—was, at least so far as I know, always made out of plain drawn material, not hardened at all, or perhaps only case-hardened. In fact, many anti-friction bearings, even now, are made from case-hardened materials. But, as stated, the modern ball bearing for heavy duty should be made from an alloy steel. There is no steel too good to use, and the steel in the ball bearings here on the table is probably the most expensive steel that we have, and when you consider that in a forged state, the cost appears almost prohibitive at first sight.

The manufacture of these bearings may be of interest to you.

In the first place, there is an inner race that goes on the shaft; then there is an outer race that goes in the housing. And rolling between those are the balls. One of the races is fixed and the other rotates; the balls are the medium by which the load is carried and through which the friction is eliminated, or partially so. In the larger sizes those races are forged, and of course forging improves the quality of the material considerably; in very small sizes the material is usually cut from the bar stock. After the race is forged up to shape approximately, it is annealed in order to remove the forging strains, and then it is rough turned down to a given tolerance which allows for both hardening and grinding; then it is hardened. After it is hardened it is again drawn very slightly to take out the hardening strain, just as a tool maker takes the strain out of the die; he does not thoroughly draw the die in many cases, but simply takes the hardening strain out, and that is what is done in the case of these bearings. They are then rough ground down to a tolerance (depending on the size) of a few thousandths, and then finish ground, which is the final operation, to a finish dimension. The dimensions of ball bearings are measured in ten-thousandths of an inch. All heavy-duty ball bearings are made in standard sizes, and those standards are measured in millimeters, because ball bearings were originally made abroad and that nomenclature has been followed in this country. The tolerances on the finished bearings are likewise measured in ten-thousandths of an inch. The tolerances are, of course, larger on the races than on the balls. Mr. Gansslen told us that the tolerance on the balls was one ten-thousandth of an inch, which is quite right, but the ball by its process of manufacture, automatically grinds itself absolutely round.

The manufacture of a ball is an interesting subject. The most general practice is to take a rod whose diameter is somewhat less than the finished ball; this is clipped off into cylinders, the cubical content of which is greater than the cubical content of the ball, to allow for finishing. This cylindrical piece is put between a couple of hemispherical dies and brought down to a roughly spherical shape. Since the edges of the die do not meet, there is a small circumferential fin, which is characteristic of such die work, around the center of the ball. That is sheared off and then the ball forging is annealed, similarly to the material in the race, to remove the forging strains, after which it is rough ground. The grinding process is the whole essence of ball manufacture. If you have ever watched a youngster take a piece of putty or gum in his hand and roll it, you know it grows round simply because he is constantly presenting a new axis of rotation. In grinding a ball, exactly the same principle is followed. The balls are placed in a circumferential groove of a large disk which lies in a horizontal plane. There is a grinding wheel below and one above, which come down to bear on the ball, but the axes of those two wheels do not coincide. Therefore a constant spinning action of the ball is set up and a new axis is always being presented to the grinding action of the wheel; that same principle is carried on through successively finer grades of grinding wheels until the result is a round, smooth ball, which has not, however, a fine polish but a dull surface. The balls are all practicaly round but not exactly the same size. They are put in an ordinary tumbling barrel, which can be sealed, and they are tumbled in that with a grinding mixture. To a very slight extent it destroys their sphericity, but only to about 0.0001 of an inch. The balls are all round when they come from that machine, and highly polished, but they are of widely different sizes. For instance, in each lot the total range may be two or three thousandths of an inch, and the balls must therefore be sorted to exact size. One widely used scheme is to let the balls roll between plates at a very slight angle to each other. When a ball comes to the place where it falls through, it falls into a pocket or container below. This is one method of sorting which, of course, is commercially adapted, so as not to be as cumbersome as it sounds, but the principle is the same.

That may give you an idea of how the ball bearing is made accurately. A ball bearing must be made accurately or it is a failure for heavy duty.

We will assume that we have the right kind of a bearing. If we put that in a mechanism, the load of which is considerably greater than the capacity of the bearing, of course failure may be expected. We will assume, in a given bearing, that we have the right materials and the right design, but that the estimated bearing capacity is not quite great enough for the load it is called upon to carry. If there are no weaknesses in that bearing due to defects in material or manufacture, then the race surface destruction will be a slow one usually, because failure in that case comes from what we call "destruction due to crystallization." Those who are interested in testing work know that we may take a piece of steel of a given tensile strength and pull it, and take another piece of that same steel, so far as we know, and subject that to slight pulling strains, the value of those increments of load, however, being small in proportion to the total stress; if that specimen be subjected to a final pull you will find its load capacity has dropped a large amount. We call that "fatigue"—the crystallization of the material due to repeated stress. Likewise in a ball bearing, if the material does not have a very high fatigue resisting capacity, it gives out. It may initially have enough strength for the load, but in time it will weaken and fail. The ordinary carbon steels are especially susceptible to that kind of strain. In railroad shops I have seen axles come in sheared off clear sometimes, as if they had been cut off with a saw. That was supposed to be due to crystallization.

Since the ball bearings of earlier days, and the one brought up in discussion, were made of carbon steel, the tendency to fatigue was especially great, while if the materials had been better the life would have been longer.

But what you are all interested in is the practical operation of ball bearings. I can say that they are running at speeds from practically nothing to 65,000 r. p. m., although 65,000 is not as yet a commercial proposition. That work has been done by one of the largest manufacturing companies in this country on its own initiative, and has not been thoroughly satisfactory, but it has demonstrated that the ball bearings can be operated to an extent at that speed. There is one large manufacturer in this country who puts out bore grinders, the speed of which is 20,000 r. p. m.; the spindle is mounted on ball bearings and nothing but ball bearings. There are other manufacturers over a wide range of machinery in all lines whose output, either in large or in small part, is mounted on ball bearings.

The use of ball bearings is especially marked in flour-mill machinery. There are two or three very large manufacturers of flour-mill machinery in this country, and their bearing conditions are very severe. The heavy rolls for shredding breakfast food impose unusually severe duty on their bearings. Many of these mills are mounted solely on ball bearings with perfect results.

Another very severe bearing condition I have in mind is in connection with what is called an attrition mill. It is used in the grinding of feed primarily. There are two large corrugated disks which run in parallel planes. These disks run all the way from 18 to 36 in. in diameter. Each is driven by a separate belt. The material is ground into a fine state from lumps of considerable size, initially. Those machines take all the way from 25 to 150 h. p. at speeds of 1,800 to 3,000 r. p. m. You will agree that this represents a severe bearing load, yet probably 50% of the attrition mills in the United States are now furnished with ball bearings alone, because of the very unusual success which has been had with them.

I mention those isolated instances as absolute proof of what is being done; scores of other such cases could be mentioned.

I want to touch, also, on railroad work, and have a number of slides showing the application of ball bearings to certain phases of that work. By railroad work I refer specifically to electric-railroad work, because all ball bearing application thus far has been confined to that field.

The use of ball bearings on railroad cars covers a period of only three years in this country. During that time a considerable number of bearings have been applied to both main journals and motor armatures with 100% success.

Furthermore, the largest manufacturers of mining locomotives in this country, as a result of complete trials, is now mounting practically its entire output as to motors on ball bearings.

From the manufacturer's standpoint, the foremost advantages accruing from the use of ball bearings are those which tend to make his apparatus more nearly foolproof and wearproof. From the viewpoint of the user the advantage is somewhat different; a large saving in energy is possible by the application of ball bearings to main journals. Motor armatures mounted on ball bearings do not show a great saving in energy—about 3 to 5%—but do not wear, commutate better, and have their temperatures materially decreased.

In various apparatus used on railways, in which the bearing conditions are very severe, ball bearings have been used with thorough success.

In concluding, I want to impress upon you that certain essentials are necessary for ball bearing success. The right design and proper selection have been brought out; the right kind of mounting is a third essential.

The bearing must be properly enclosed against the entrance of foreign material from the outside and to assure the retention of lubricant around it. The enclosure which is ordinarily used is called "lip and groove closure," consisting of a pair of lips snugly fitting the shaft, with a groove in between, the edges of the lips being sharp and serving admirably as a seal. This groove is usually drained at the bottom to the inside of the bearing housing.

As in plain bearings, the user must take care that grit is not allowed to enter the bearing, because more or less cutting out will result.

Lubrication attention is, of course, not so necessary, because the chief action of lubricant in a ball bearing is to protect its finely polished surfaces against the action of moisture in the atmosphere. An occasional filling of the housing is amply sufficient to insure a reasonable amount of lubricant around the bearing, providing the mounting has been satisfactory.

I hope that these practical ideas on the subject of ball bearings may be of some interest to you, taken in connection with the valuable theoretical data which Mr. Gansslen has given.

Mr. Gansslen: One of the speakers inquired as to the materials used. Unfortunately, the selection of material is a trade secret. Before the first successful ball bearing was put on the market some years ago, the concern developing the same had spent about $75,000 for the testing of the material, and finally the discovery of the proper material was one of the most expensive items. However, I would venture to say that probably the material best adapted to the manufacture of balls and ball races is an alloy steel which contains a considerable amount of chromium. This information I am taking from the literature more than from anywhere else. I am very sorry that a fuller explanation is not available.

As to Mr. Symons' remarks about the ball bearing being in its experimental stage, this is true in this way: It will always be in an experimental stage, we hope, because the field of application is widening every day, and that is what we want; but there have been undoubtedly so many fields of application covered successfully that we have reason to be proud of the results.

Mr. Batt: Broadly speaking, very high grade of alloy steels are used. There are a number of different kinds, different chemical compositions—just as many as there are manufacturers, for that matter—but they all attempt to fulfill that requirement of extreme high fatigue capacity. Of course, they are cast steels.

Mr. McCullough: The term trade secret, of course, does not have the extremely narrow meaning it had a generation ago. In its broader sense it simply means that as yet certain work is largely in an experimental stage and those interested are seeking for perfection. In former days the term trade secret meant something the discoverer did not want others to get hold of.

CHICAGO RIVER TUNNELS—THEIR HISTORY AND METHOD OF RECONSTRUCTION

William Artingstall, M. W. S. E.

Presented October 11, 1911, before the Bridge and Structural Section.

The problem of the lowering of the tunnels under the Chicago River has been before the public so often during the past five years that the majority of the people heaved a sigh of relief when the Secretary of War, acting under a law of Congress, declared (what most of us already knew) "that the tunnels under the Chicago River at La Salle Street, Washington Street, and the one just north of VanBuren Street, were, each and all, a nuisance and should be removed." Officially that was enough—practically it was a stick prodding a hornet's nest. This resulted in two or three years of litigation from one court to another until a decision of the United States Supreme Court compelled the lowering of the tunnels.

During all this time there were just as many people demanding transportation to and from the downtown district, and the demand had to be satisfied—at least, partially. So it was entirely out of the question to abandon the tunnels until some provision was made to replace the cable cars on Madison Street, Milwaukee Avenue, Blue Island Avenue, Clark Street, Clybourn Avenue, Wells Street and Lincoln Avenue.

After the dose of "branch and twig" theory and the "municipal ownership physic" somebody happily thought of the "compromise plaster." This proved to be the right medicine and the public grew strong enough to throw off its blankets of theories and "isms" and the City Council drew up an agreement with the street railway company whereby the latter were to electrify their cable routes and lower the tunnels.

The VanBuren Street Tunnel is built on private property, north of VanBuren Street, and is owned by the Chicago Railways Company; while the Washington and La Salle Street Tunnels are owned by the City of Chicago. The two former tunnels pass under the South Branch of the Chicago River and connect the downtown district with the West Side, while the La Salle Street Tunnel passes under the main Chicago River and connects the downtown district with the North Side.

The maximum depth of water over these tunnels was 18 ft. This depth of water proved sufficient for some years, but, when the river level was materially lowered by the reversing of the current, due to the opening of the Sanitary and Ship Canal, considerable complaint was made by navigation interests and the Commercial Association. This resulted in Congress passing an act, approved April 27, 1904, entitled "An act declaring each of the tunnels under the Chicago River an obstruction to navigation and for other purposes." and further providing "that the tunnels under the Chicago River in the State of Illinois, at La Salle Street, Washington Street and near VanBuren Street in the City of Chicago, State of Illinois, are and each of them is hereby declared to be, as now constructed, an unreasonable obstruction to the free navigation of said Chicago River, and each of the said tunnels is hereby declared to be a public nuisance." The same act also provided that the Secretary of War recommend such changes "that said tunnels shall not thereafter be an obstruction to navigation," etc.

This act was upheld by the Illinois Supreme Court and on April 9, 1906, the United States Supreme Court affirmed the decision of the former, directing the issuance of a writ of mandamus to compel the lowering of the tunnels so as to provide a clear depth above said tunnels of at least 21 ft. for the full width of the tunnels between the existing dock lines, or to wholly remove the tunnels.

Under a compact with the City of Chicago, the Receivers of the Union Traction Company agreed to lower all three tunnels; and the City Council passed an ordinance June 18, 1906,* entitled "An ordinance to provide for the lowering of the tunnels under the Chicago River and for the temporary operation of certain street railway lines by electricity." This was accepted by the Receivers of the Union Traction Company.

The plans and specifications for the work were prepared by Mr. Samuel G. Artingstall, M. Am. Soc. C. E., and Past President of the Western Society of Engineers, who was retained as Chief Engineer until he resigned on January 31, 1907. All detail plans, surveys, etc., were made and the prosecution of the work on the three tunnels was carried out under the direct supervision of the writer, as Engineer in Charge. Mr. John Z. Murphy was Chief Engineer of the Union Traction Company, and R. W. Hunt Company the Inspectors.

The plans and specifications having been prepared, eleven bids were received for doing the work in each of the three tunnels and the extreme variation in the bids is interesting.

On the VanBuren Street Tunnel the lowest bid was $147,511, while the highest was $289,200.

On the Washington Street Tunnel the lowest was $39,950; the highest $171,000.

And on La Salle Street Tunnel the lowest was $65,000, while the highest was $242,000.

In order to understand the work about to be described, I will take up each of the three tunnels separately and introduce them with a short historical description.

THE VAN BUREN STREET TUNNEL.

The VanBuren Street Tunnel (Fig. 1) was built in 1893 by the West Chicago Street Railways Tunnel Company—of which Mr.

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*See Council Proceedings May 28, 1906.

Samuel G. Artingstall was the Chief Engineer—to accommodate the cable line which was then being built on Blue Island Ave., and is located between Clinton and Franklin streets, just north of Van Buren Street.

The tunnel is a three-centered brick arch 30 ft. span at the springing line, and 20 ft. in height from the invert to the crown of the arch. The east and west approaches are respectively 142 ft. and 303 ft., while the tunnel proper is 1,052 ft., making a total length of 1,517 ft. from end to end of approaches. The brickwork was all laid in Utica cement mortar except the two outer courses, which were laid in asphalt. On top of and surrounding the brickwork is a course of concrete, varying in thickness from 2 to 3 ft. (Fig. 2). The floor of the tunnel was an inverted arch, 2 ft. thick at the center and about 3 ft. thick at the sides. A Bedford stone skewback separated the arch and invert.

The west 500 ft. of the tunnel is directly under the Pennsylvania Railroad yard, while the east 300 ft. support four seven-story brick buildings.

Unlike those for the other tunnel, the plans for the work at this tunnel contemplated the entire remodeling of the tunnel as summarized below:

1st—Building a new steel girder and concrete roof in the river section.

2nd—Building bulkheads at each end of the new roof.

3rd—Cleaning out old track, cable yokes, etc.

4th—Lowering the invert and underpinning the old foundation for practically the full length of the tunnel.

5th—Rebuilding the pump chamber and well.

6th—Removing the old roof in the river section.

These will be taken up in the order followed during construction.

New Roof:

The new roof was built only in the river section, and consists of fifty-three 32-in. steel girders 32 ft. long, with concrete jack-arches between them. These girders rest on 15-in., 80-lb., I-beam columns 4 ft. 3 in. centers, set in chases cut in the brick arch. Over the entire roof and extending up into the bulkheads, was laid a waterproof course of brick imbedded and flushed with a hot asphalt compound. This is protected by a 12-in. course of concrete.

As the new roof was to be completed before lowering the invert, chases for the I-beam columns were first cut in the sides of the existing arch (Fig. 3). These chases were approximately 2 ft. wide and 20 in. deep at the base, while at the top the depth varied from 18 in. to 3 ft. This variation was due to the difference in grade of the old arch and the new roof (Fig 1.).

The first girders were delivered to the tunnel on September 26, 1906, but were rejected on account of poor workmanship. The first girder was set on October 29, 1906, and the last one on November 19, 1906. The buckle plates were abandoned, so the cover plates were riveted to the girders and the columns concreted in place by December 1, 1906.

The tunnel portals were then barricaded for winter and forms erected for jack arches between the girders. All the material for concrete was delivered into the tunnel on wagons and stored near the west end of the new roof.

As the temperature in the tunnel never fell below 50 deg. F., the concreting continued day and night until completed on Janauary 12, 1907. All the concrete was mixed by hand on platforms placed beneath the new roof, loaded into box barrows and hoisted by means of a hand winch to the top of the new roof. In dumping the first few batches of concrete in each arch, considerable difficulty was experienced in keeping the stone from "rattling" away from the mortar and collecting along the lower flange of the girders, from where it was almost impossible to recover. To remedy this about 4 in. of mortar was first spread along the flange and then worked into the loose stone. The result was all that could be desired. The concrete was mixed wet and thoroughly puddled while being placed. Two shifts were employed on the work and in almost every case work continued until the concrete between any two girders was all placed. A 3-in. course of concrete was then spread over the entire roof. This was allowed to set and thoroughly dry for two weeks

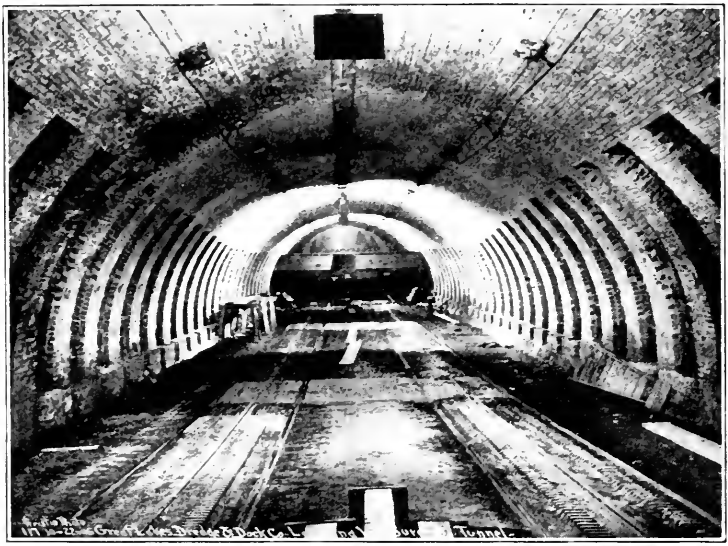


Fig. 3

before starting the waterproof course. Meanwhile the brick arch over each girder was cut away for a width and height of about 2 ft., clear back to the old waterproofing. These openings were then cleaned out and slushed with pure asphalt at a temperature of about 350 deg. F. Hard sewer-bricks were then imbedded therein and flooded with the same asphalt mixture.

The specified waterproofing was one course of brick and a mixture of asphalt and gypsum, but so much trouble was encountered by foaming that this mixture had to be abandoned and a mixture of asphalt, asphaltic cement, and marble dust substituted. This retained the heat longer, gave no trouble in the boiling pan and adhered better to the bricks. But, like the other, the new mixture would not adhere to concrete. To remedy this feature, a second course of brick with 1½-in. joints was imbedded in the filler course of asphalt, and the upper part of the joints filled with cement grout. The water-proofing was started on February 4 and finished on February 16, 1907. On February 18, 1907, the east bulkhead was started, as also was the weakening of the old arch. The roof was finished in a couple of days and on March 4 a beginning was made to build the west bulkhead. This bulkhead extends westerly from the present dock line, and about the east half of it lies in the proposed 200-ft. river section. Notice of this fact was taken in building the bulkhead, which was planned accordingly.

During the construction of the bulkheads, the old arch was systematically cut away over each girder for a distance of 2 ft. longitudinally and the same in height. These openings were then blocked with oak wedges which left intermediate spaces of about 2 ft. width that were afterwards partially cut away and blocked up. All the material cut out was piled on the new roof to form a cushion, and to this was added all possible debris and filling from the tunnel. The bulkheads were closed up on March 19, 1907.

Lowering Invert and Underpinning Side Walls:

On March 19, 1907, the contractors began the removal of the car tracks, cable yokes, and road bed, which amounted to:

2,400	lin. feet of track,
610	cable yokes,
2,400	lin. feet cable slots,
4,000	cubic yards of filling,
120	cubic yards of concrete saddles,
1,000	square yards of brick pavement,
3,000	square yards of cedar block pavement.

This removal was completed by June 3, 1907, and exposed the full length of invert that had to be lowered. A mixing platform was then built at the west end of the proposed work near the west portal and a double narrow-gauge track was laid from this point to the dumping platform at the east end of the tunnel at Franklin Street. The mixing platform was about 8 ft. above the track level, so the concrete was spouted directly from the mixer to the cars. These were lowered down the incline by means of an electric hoist located directly beneath the mixer. The cement, sand and stone were teamed down a planked roadway to the mixer.

At the center of the dumping platform, which was about 8 ft. above the sidewalk at Franklin Street, an electric hoist was located with a track on either side. These tracks accommodated two cars of excavation or just a wagon load. As soon as one car was dumped, the wagon was moved under the other car and the first car was lowered into the tunnel. The cable was then hooked onto a loaded car which would be raised to the dump and was in position by the time another wagon was in place. The second car was then sent below and the operation repeated. All the hauling was done in the morning and as many as 160 cu. yds. of excavation were taken out in five hours. This, however, was an exception, for almost every day the lack of teams caused untold delays, and some days as much as two or even more hours would be lost on account of the scarcity of teams. The excavated material would then have to be spoiled along the sides of the tunnel and afterwards hauled out.

In starting this work the entire length of the tunnel was marked off in 5-ft. sections with five sections to a series. Excavating was then begun on Sec. 1 of Series A, then on Sec. 1 of Series B, and so on to Sec. 1 of Series G. As it usually took at least a week to finish a section in each of the seven series, we could then go back and start on Sec. 2 of Series A, knowing that the new concrete had a good seven days' set before the underpinning on the adjoining section was started. This system was followed throughout the entire lowering of the tunnel.

The underpinning was carried on simultaneously with the lowering of the invert. No difficulties were encountered other than those to be expected in an undertaking of this character where it is not known what is ahead or beside the work, and where the existing work was not planned with a view of putting it on stilts. The main difficulty, however, was from places where the foundations were poor, at which places, unfortunately, water was always encountered, and also old piles from the cofferdam used in the construction of the tunnel. These piles were encountered in almost every section, sometimes within a few inches of the inside face of the tunnel and at other times farther back under the walls. A testing needle was used in every case and almost invariably showed that these piles were the outside limit of the walls, beyond which we could not go. In case the needle encountered something hard beyond the pile, we carefully followed back along the concrete and in some cases managed to get an extra foot of thickness for the foundation. Too often, however, we were disappointed and the new foundations had to be reinforced.

For this reason the face of the foundations was moved 9 in. into the tunnel in order to obtain the requisite width at the base.

The excavation varied in depth from 2 to 12 ft., and the material varied from soft blue clay to hard-pan. A number of pockets or rather lenses of white sand were encountered, which was as fine as flour and flowed like water. One of these lenses was about 15 ft. wide, 2 ft. thick, and extended clear across the tunnel and under the walls.

Drainage:

The new drainage system consists of a pump well located in the north wall just east of the new roof and two sumps, one directly opposite the pump well and the other approximately in the center of the river section. The west approach to the tunnel is drained by a 12-in. vitrified pipe laid along the invert to a catch basin at the middle sump, and thence through an 18-in. pipe laid under the invert at a 1 per cent slope to the sump opposite and connected with the pump well by an 18-in. pipe. The east approach is drained by a 12-in. pipe laid along the invert and emptying into the sump opposite the pump well.

Pump Well:

As will be seen by referring to Fig. 4, the track level at the pump well is about 22 ft. above the drain from the center sump. As this made nearly a 30-ft. suction on the pump, it was necessary to build a pump chamber below the track level. This was a dangerous operation on account of having to underpin the walls on either side of the old pump well which had a 6-ft. by 5-ft. opening, was 9 ft. high, and had a 5-ft. shaft leading to the boiler room of the building above the tunnel. Directly over this section are the columns carrying the floors of a double seven-story building. The footings of the columns are carried by the tunnel arch. This brought approximately 30 tons per lineal ft. on the foundation at this point. The corners of the old pump chamber had been eroded by water and ice until the opening was increased 2 ft. beyond its original width, thus concentrating the load on a smaller bearing area and necessitating the greatest care and caution in prosecuting this section of the work. The poor brickwork was carefully cut away, the corners squared, and a solid wall of vitrified brick built across the face of the former pump chamber. Two I-beams were built in this wall, and an eye-bolt, for raising and lowering the pumps, was projected through the small arch which forms the base of the wall. It was then the intention to underpin the corners of the pump chamber, but shortly after starting a bed of fine sand was found which seemed to pass directly under the east corner of the chamber. This sand, though absolutely dry, flowed like water, and, not caring to undermine the wall, we changed the procedure and gradually underpined the wall to the east and west, thus working toward the pump chamber a few feet at a time. When within 2 ft. of the corners, we cut away the face of the old pump well and underpinned the remainder by "legging" down 5 ft. at a time until the bottom of the chamber was reached. The floor was then put in and the first 8 ft. of the pump well excavated.

Brick laying had just begun when water flowing down the shaft drowned out the brick-layer and began caving in the sides of the well. This was hastily sheeted up and braced and provisions made to build a concrete well. When everything was ready, the water was pumped out, the well cleaned up, and the sheeting removed. A drum was then lowered to place and concrete quickly dumped around it. The drum was allowed to remain in place for three days, when it was knocked apart and the remainder of the well sunk without any difficulty. We afterwards had a grout machine brought down to the tunnel and pumped 65 bags of cement behind the wall of the old shaft. This has effectively stopped the leakage and the shaft is now practically dry.

A few days after, January 13, 1908, the contractors started to remove the old roof. They had not proceeded far, however, when so much water began to come in through the old concrete beneath the stone wheel guard that it semed expedient to stop the dredge until the concrete could be repaired. The old concrete was then cut away for a depth of 8 to 12 in., and in places as much as 2 ft. Several deep holes were found which seemed to have a direct connection with each other back of the solid concrete. A one-inch bleeder was put in each of these and projected out through the forms which were erected along the length of the old work. The old concrete was then replaced by a mixture of one part cement, two parts sand, and one part very fine gravel. This was mixed quite wet and thoroughly puddled. The bleeders were left open, and although for a time they flowed full, no water has come through the concrete.

On February 10, 1908, the new pump was installed in the pump chamber and on the same day, the contractors started to drill the old roof before putting the dredge to work. The drilling was done by Drill Boat No. 1, belonging to the contractors. The holes were drilled about six to ten inches apart and about two or three feet longitudinally. Near the dock lines the holes were drilled as closely together as possible. Considerable water leaked into the tunnel shortly after the drilling started, but the number of leaks and quantity of water continually decreased as the drilling progressed. After the old roof was removed, a blanket of clay was spread over the tunnel, and as this settled into place the leakage still further decreased. The few leaks which remained were choked up by first cleaning out the hole and inserting a thin lead pipe about 4 in. long. This was held in place by a mastic of clay and cement and the adjacent surface carefully plastered a little at a time until the pipe carried all the leakage at that section. Two or three days elapsed before the pipe was plugged with oakum and cement and clinched. Sometimes the water would break out in a fresh place, but by repeating the operations, as above, and allowing the pipe to remain open a few days longer, we succeeded in stopping practically all leaks in the new work. Those that could not be stopped up have been piped and the water is carried down the walls in pipes to the drain under the track.

The Great Lakes Dredge & Dock Company were the contractors for this work and their superintendent in immediate charge was Mr. Thos. Osborn, who is so well known among us that anything I would say as to his ability has been already said many times in the past.

WASHINGTON STREET TUNNEL.

The construction of this tunnel was first authorized by an ordinance passed by the City Council in 1865, which appropriated the sum of $100,000 in city bonds, under the condition that a similar sum be raised by popular subscription. Mr. Gindele, then President of the Board of Public Works, prepared plans and specifications for the construction of the tunnel, but the public subscription failed, so the Council then passed another ordinance which provided for the construction of the tunnel by the Board of Public Works. Nineteen bids, ranging from $247,000 to $430,000, were received and opened in August, 1866. Stewart, Ludlam & Co. were awarded the contract at $271,646, and commenced work the following October, but lack of capital prevented the contractors from fulfilling their contract, and they abandoned the work in May, 1867. In June the abandoned section of the east side of the river caved in. In July, 1867, a contract was made under new plans and specifications, with J. K. Lake, C. B. Farwell, and J. Clark. The entire construction was made in open cut. Half of the river section was put under construction at a time, and when this was completed, a cofferdam was built from the opposite shore, and extended partly over the completed tunnel. The work was then carried on without serious difficulty or trouble, except that experienced from vessels colliding with the cofferdam, causing it to leak. The major part or land portion of the tunnel was constructed as a single bore with a segmental arched roof of 10 ft. radius. Just before passing under the river, however, the section was changed to a triple bore tunnel. The two northern bores were given up to vehicular traffic, while the southern bore was reserved for foot passengers, whose means of ingress and egress was a stairway at each end connecting with the street level. The tunnel was constructed of brick, laid in a mixture of lime and cement, while the foundation and outer course was of rubble stone. Arched openings 3 ft. wide afforded ventilation and communication between the tunnels.

The total length of the tunnel and approaches was 1,520 ft.

The contract price was $328,500, but the final cost was $512,709.

For some years the tunnel was used quite extensively, and after the Chicago fire of 1871 the Washington Street Tunnel was the only means of communication between the west side of Chicago and the business district, until the burned bridges were restored. The tunnel, however, fell into disuse before many years, and lack of repairs put the pavement in such a condition that traffic through the tunnel was almost, if not quite, diverted to Madison or Randolph streets. This was the condition in the late '80s when the street railways were contemplating a change from horse cars to rapid transit cable line; consequently the City Council was ready and willing to turn the tunnel over to the street railway company on very acceptable terms, the one condition being that the company lower the roof so as to give 17 ft. of water instead of the 14 ft. that then maintained.

Remodeling in 1889:

The necessary ordinances having been passed, Mr. Samuel G. Artingstall was commissioned to prepare the necessary plans and specifications for the work. The roof and center wall were torn out, the north wall strengthened, and a new roof built. This roof was composed of 20-in. steel girders, spaced 3 ft. centers with brick jack-arches between them. The arches had a rise of 8 in. and were built of three rings of brickwork, the outer ring being laid in asphalt. The floor was lowered 2 ft. 6 in. to give the necessary headroom for cars. As a center-pier bridge was to be supported on the tunnel, the section under the center pier was built as an arch of 20 ft. span and rise of 6½ ft. The old foot-passage was practically abandoned except by the telephone, telegraph, and electric power companies, who vied with each other in usurping space.

FitzSimons & Connell were the contractors and William Innes their superintendent. The final cost was about $135,000.

Remodeling in 1906:

The work completed in 1907 (Fig. 5) consisted in building a new roof under the river section, tearing out the south wall of the roadway, building new foundations in the old foot-passage, building water-tight bulkheads, and finally the removal of the old roof and center pier of the bridge. All construction work was done inside the tunnel under cover of the existing roof, which was not disturbed until the new work was completed. The roof, etc., was then removed without the use of explosives or cofferdams.

As all but one of the old openings in the intermediate wall had been bricked up in 1889, it was not possible to directly check the transit line through the foot passage with the one through the main tunnel until the contractors started to work. After an opening had been cut through this wall, the two lines were "tied in" and checked with an error of only 0.015 ft. from parallel and 0.041 ft. in length. The surveys through the tunnel were made nights between 12:45 A. M. and 5:30 A. M., and were completed before the tunnel was vacated by the cable cars on August 18, 1906.

The foot passage had been occupied by the cables and wires of several different corporations for many years and, while some of the companies removed their cables promptly on receiving notice to vacate, the last was not removed until October 7, 1906, when the Chicago Telephone Company made its final cut-over to the Chicago Edison Company's tunnel. The contractors, Angus Bros. & Co., barricaded the tunnel on August 23, 1906, and on September 14, 1906, they started cutting chases in the north wall to receive that end of the girders for the new roof. On September 29, 1906, a test pit was dug in the old foot-passage, and showed a serious discrepancy of concrete in the old floor. The original plans indicated approximately 4 ft. of solid concrete, and it was the intention to build the new foundations without disturbing these any more than necessary. The test pit showed only 20 in. of poor brick-invert overlying about the same thickness of brickbats and cinders. This necessitated carrying the foundations down about 4 ft. through soft blue clay and below the old south wall, the foundation of which was only 12 ft. below the river bed. An inspector, stationed here continually, prevented the excavation of a length more than 12 ft. at any one time; then the new concrete was placed and the section finished as quickly as possible. No section was left uncompleted over night. While this work was being done, openings 2 ft. wide by 3 ft. high were cut in the walls at every fourth girder point and securely wedged. The foundations were finished on November 3, 1906.

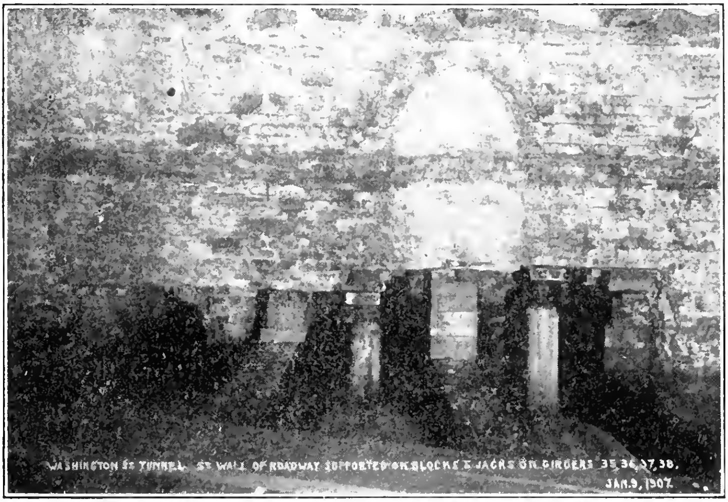

WASHINGTON ST TUNNEL. ST WALL OF ROADWAY SUPPORTED ON BLOCKS & JACKS ON GIRDERS 35,36,37,38.
JAN.9,1907.

Fig. 6

As the bottom flange for the girders is below the old track level, except for about 30 ft. at either end, the tracks and old cable yokes were torn up and a plank roadway laid while awaiting the arrival of the girders, the first of which was delivered on November 28, 1906.

On December 1, 1906, the first girder was set and cutting was immediately started for the second, so by the time the first girder was in place, and the wall above it wedged up, the opening for the next girder was ready. This procedure was followed from beginning to end, and no settlement of any kind was found in the old walls. The setting of the girders was a slow and awkward job on account of the wall between the foot passage and roadway, which wall was at about the south third of the girder (Fig. 6). It necessitated shoving the girder through a small opening as far as possible into the foot passage and at about 70° with it, then swinging the north end until opposite its opening and finally bringing the girder north to position. The girders are 30 ft. long, 33 in. deep and weigh approximately 4½ tons each. They are set 4 ft. centers. About three girders were set per day.

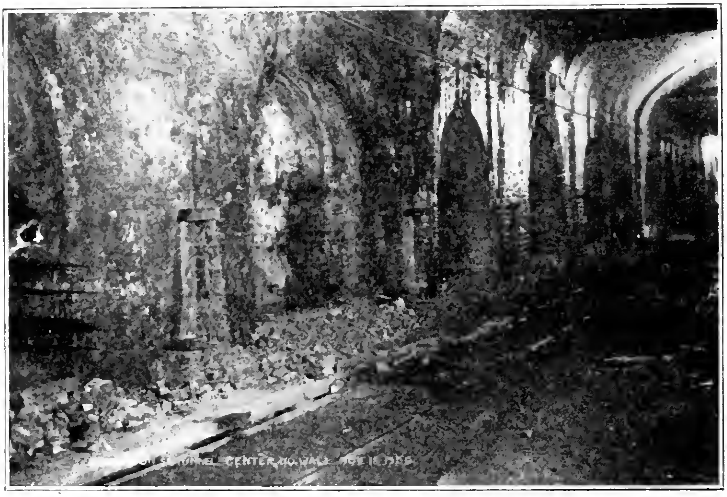
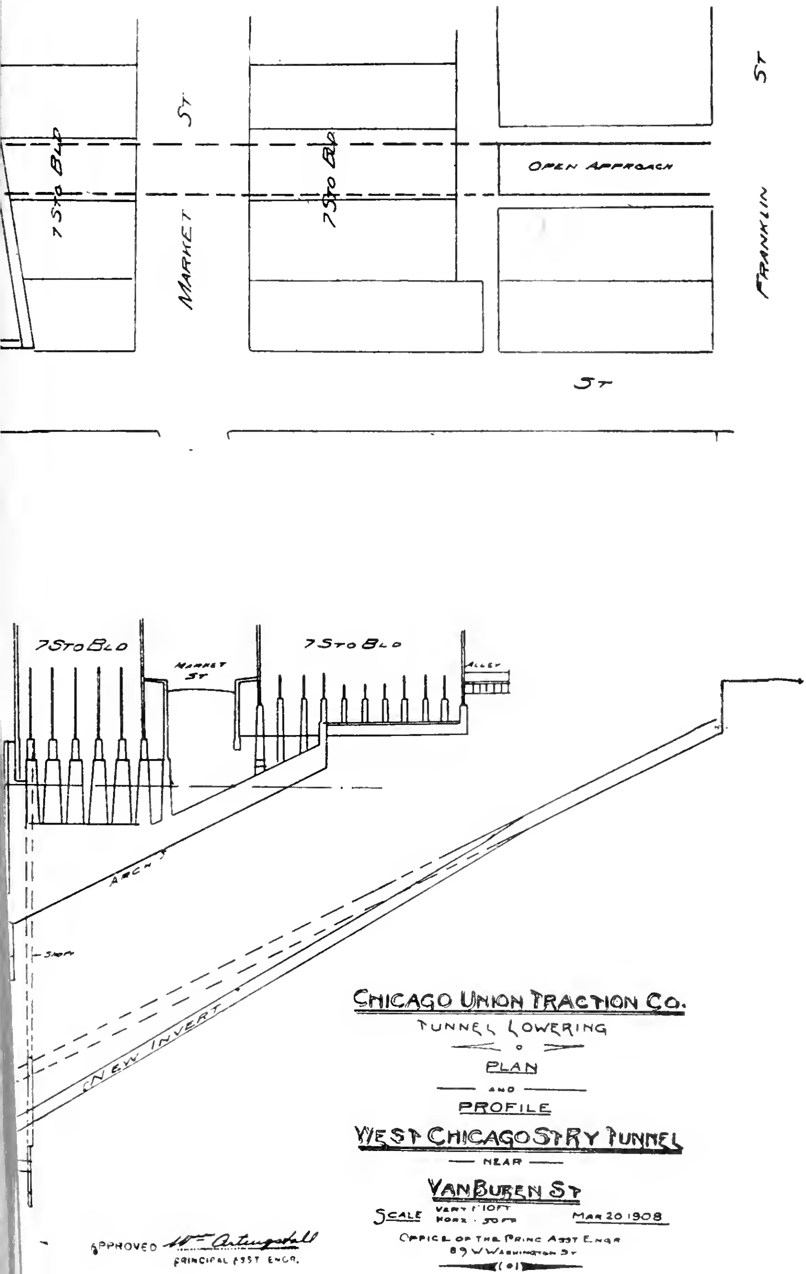
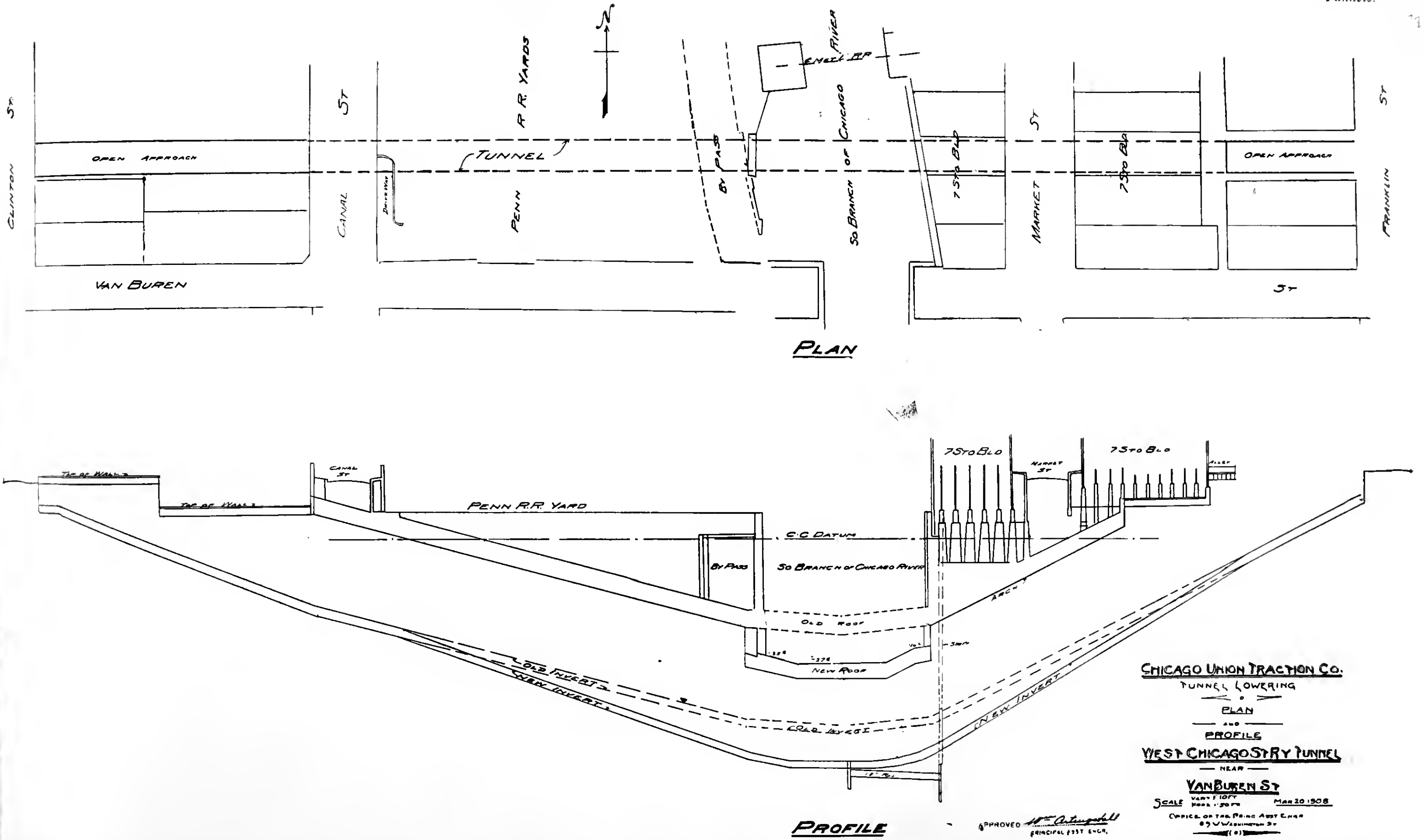


Fig. 7

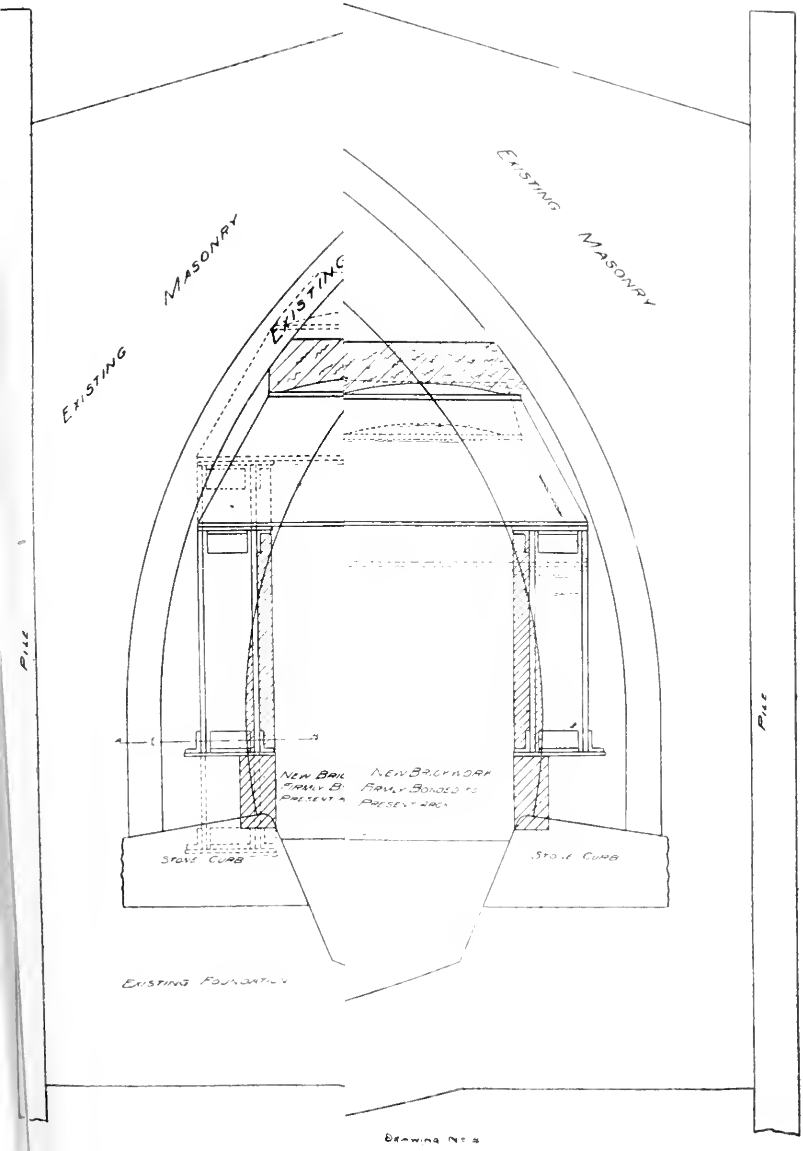
Before concrete was placed between the girders, the intermediate wall was carried by needle beams and the old roof shored up by means of drums supported by heavy timbers carried on the new girders. The needle beams (15-in. I-beams) were set three to a series, and each series 4 ft. centers; these were carried by jack screws with maple collar blocks resting on 14 in. by 14 in. timbers laid two on each side and parallel with the wall, the space between each pair of timbers being just sufficient to admit the free end of



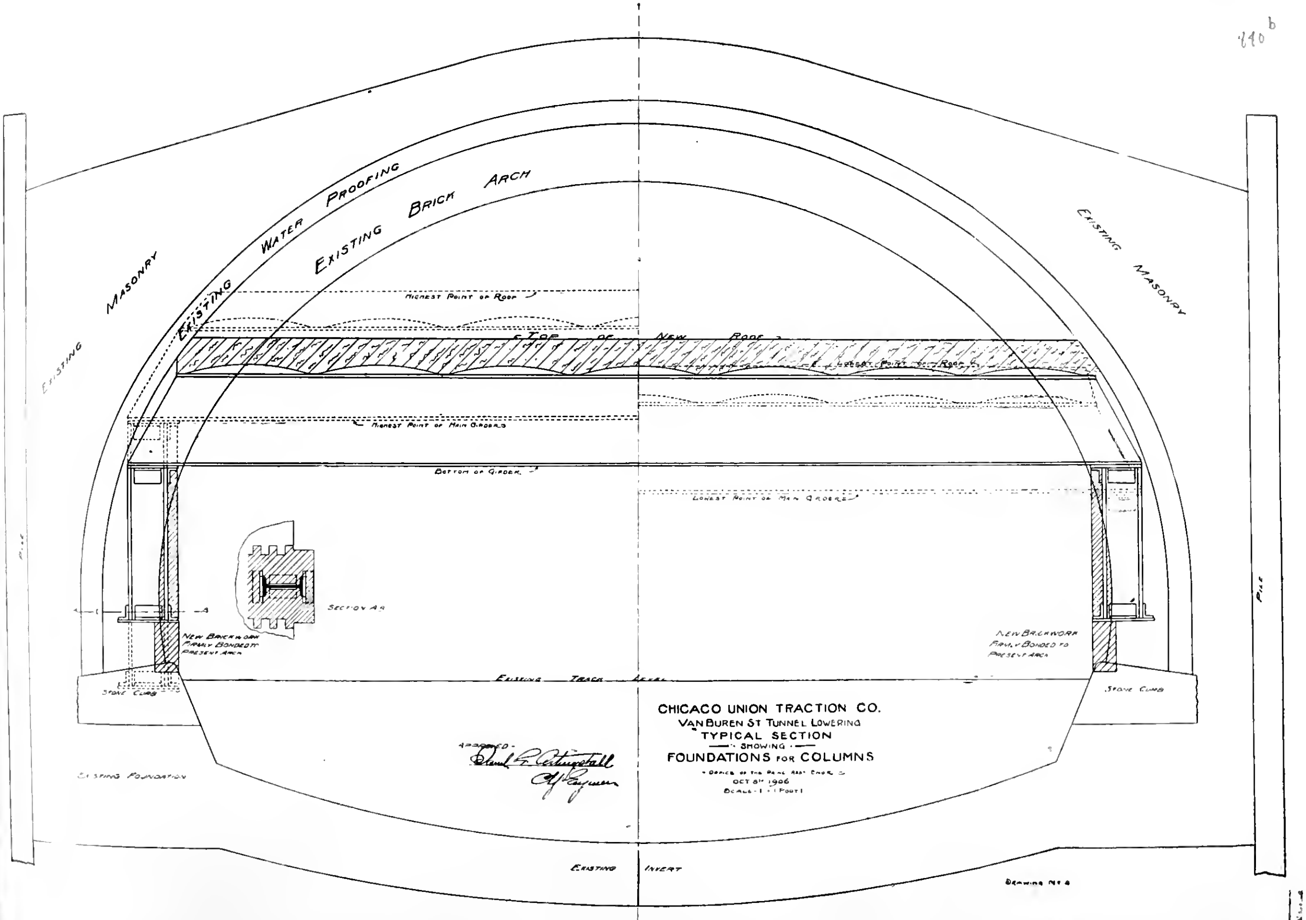
Van Buren Street Tunnel. Fig. 1.



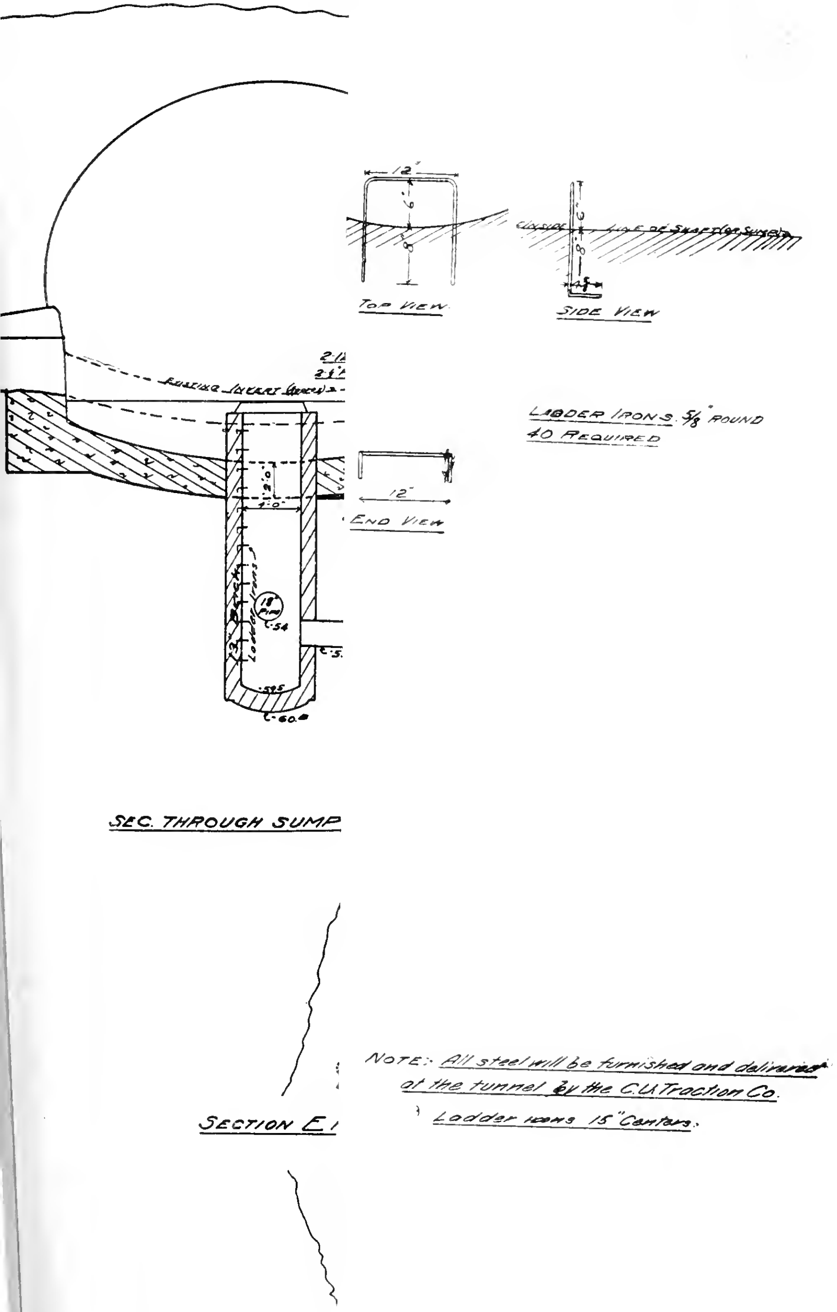
Van Buren Street Tunnel. Fig. 1.



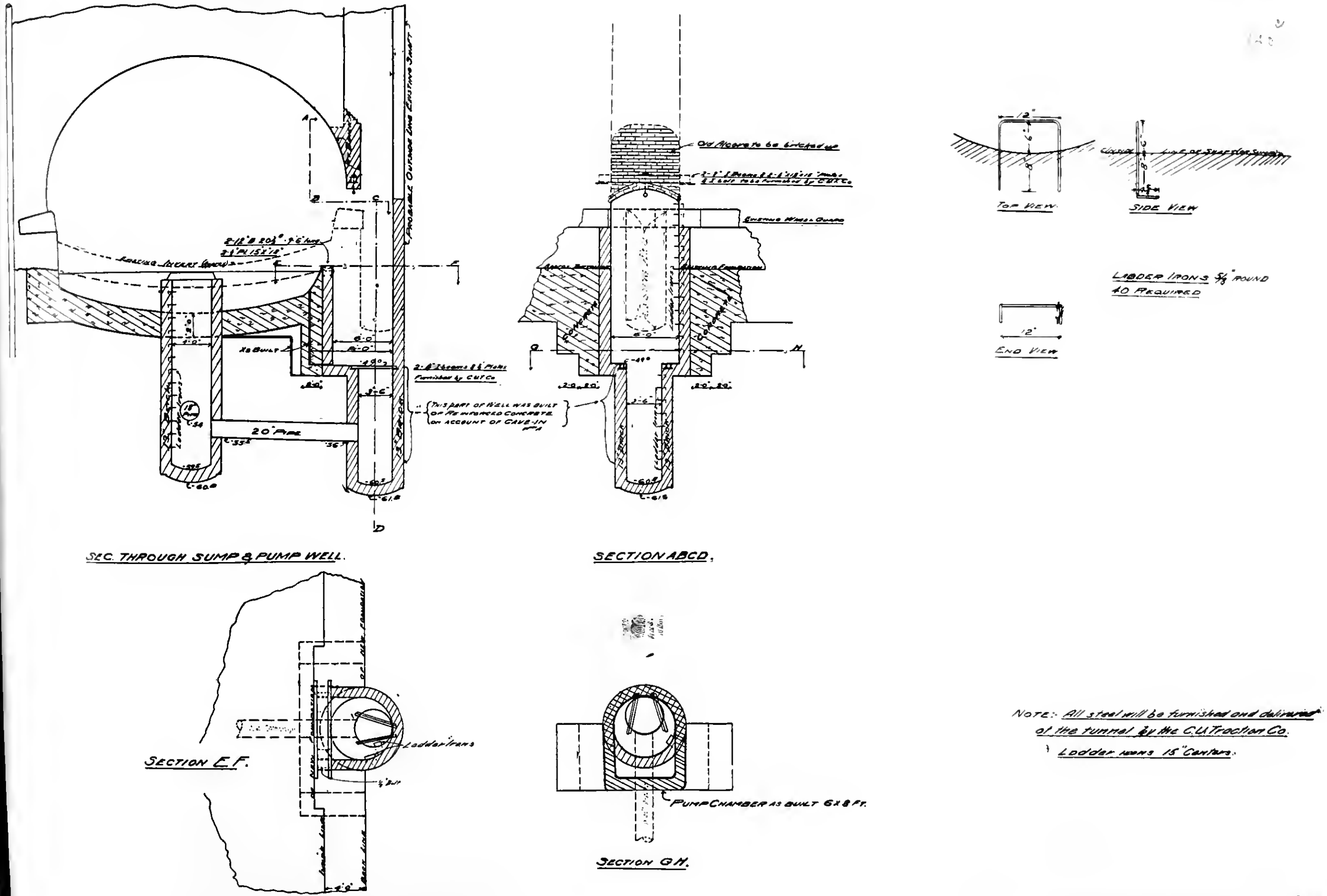
Van Buren Street Tunnel. Fig. 2.



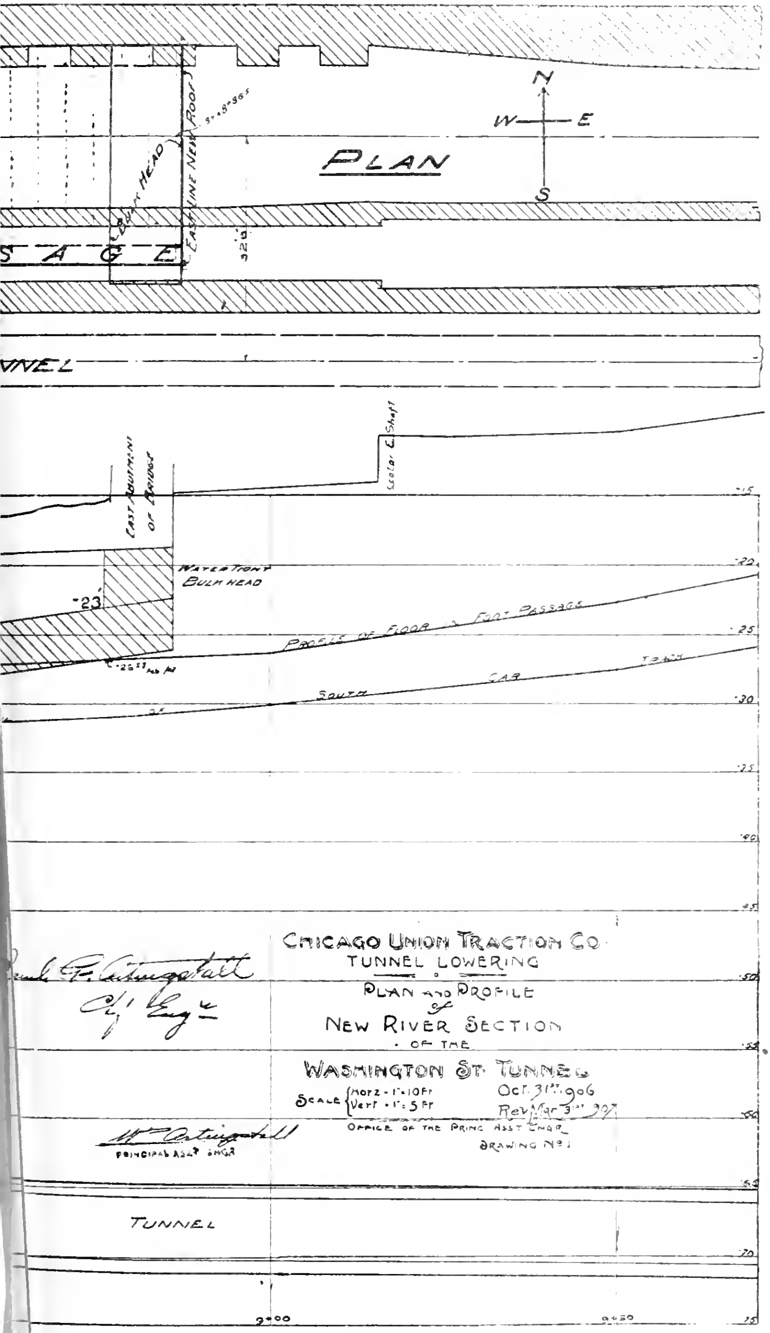
Van Buren Street Tunnel. Fig. 2.



Van Buren Street Tunnel. Fig. 4.

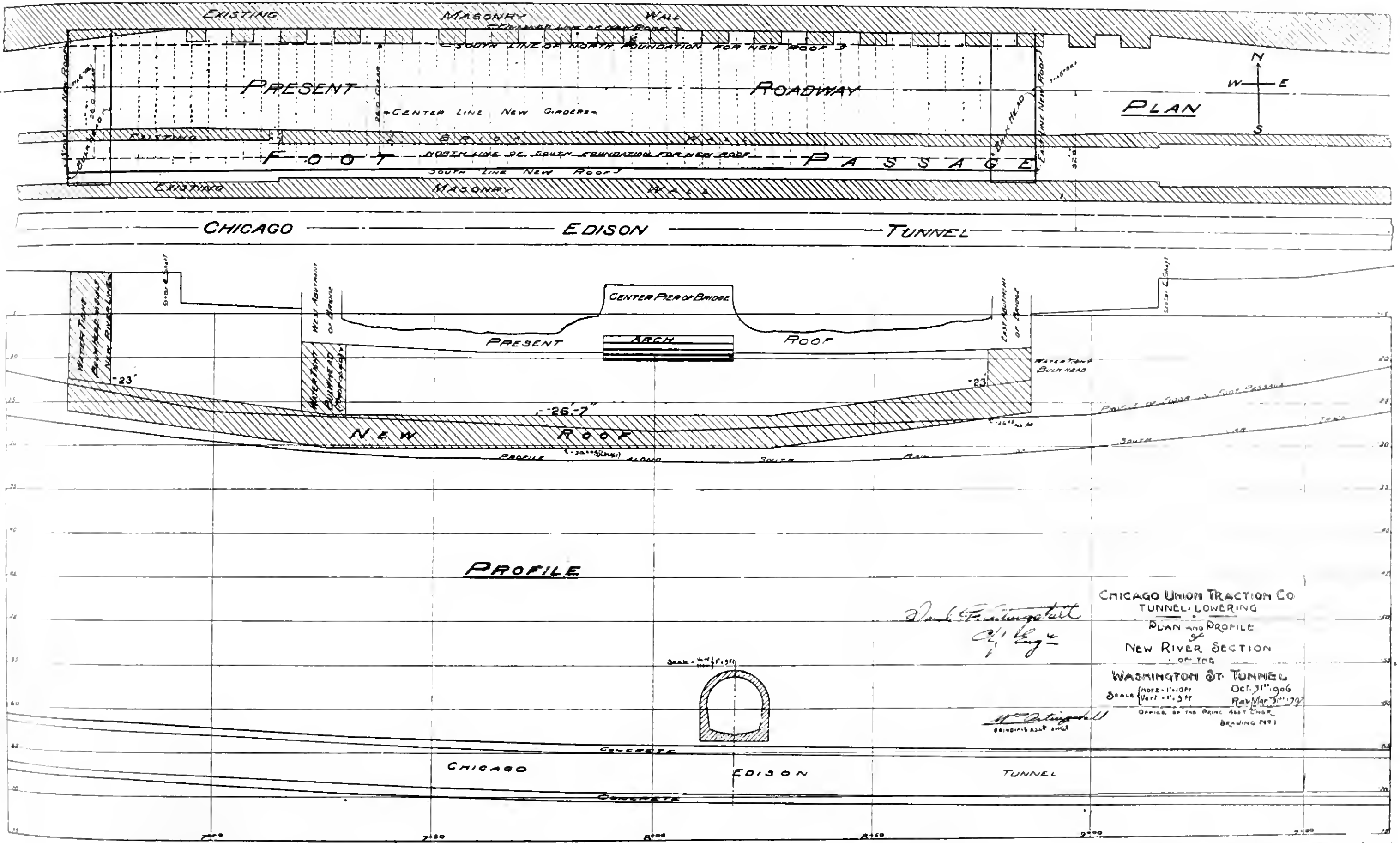

PROBABLE OUTSIDE LINE EXISTING SHAFT
A
B
C
D
E
F
2-12" B 20½# - 9'6" long
2-½" PL 15"x18"
Existing Invert (Vaults)
2'0"
4'0"
As Built
6'0"
8'0"
-49.0
8'0"
3'-6"
2-8" I beams & ½" Plates Furnished by C.U.T. Co.
This part of Well was built of Reinforced Concrete on account of Cave-in
15" Pump
-54
20" Pipe
-55.5
-56
-59.5
-60.8
-60.5
-61.8
SEC. THROUGH SUMP & PUMP WELL.
Old Alcove to be bricked up
2-8" I Beams & 2-½"x15"x18" Plates & ¾" bolt to be furnished by C.U.T. Co.
Existing Wheel Guard
Existing Foundation
Concrete
Ladder Irons
G
H
2'0"
2'0"
3'-6"
-49.0
-60.5
-61.5
SECTION ABCD.
Top View.
Side View
End View
12"
6"
8"
Line of Shaft (or Sump)
Ladder Irons ⅝" Round 40 Required
SECTION E.F.
Ladder Irons
¾" Bolt
Inside Line
Back Line
Line of New Foundation
4'0"
SECTION GH.
Pump Chamber as built 6 x 8 Ft.
NOTE: All steel will be furnished and delivered at the tunnel by the C.U. Traction Co.
Ladder irons 15" Centers.

Van Buren Street Tunnel. Fig. 4.

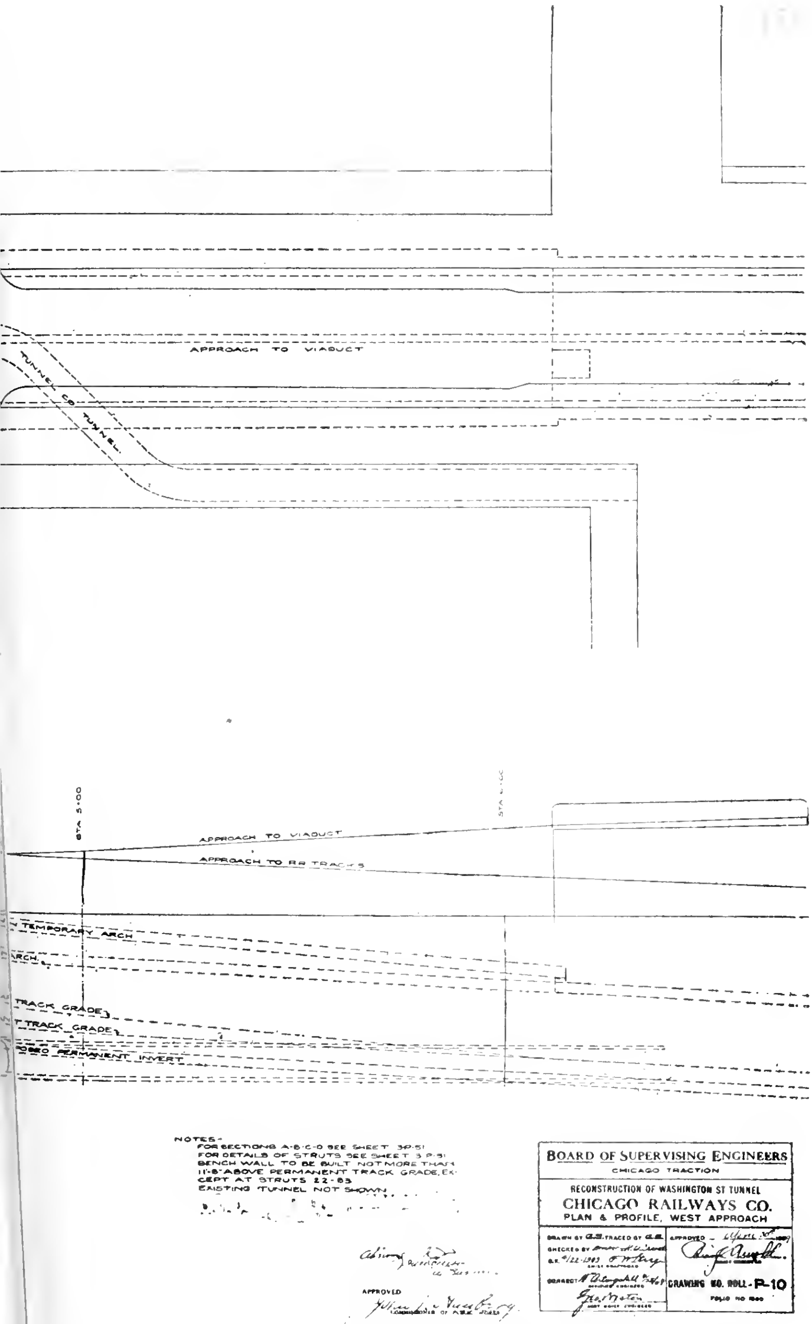


Washington Street Tunnel. Fig. 5.

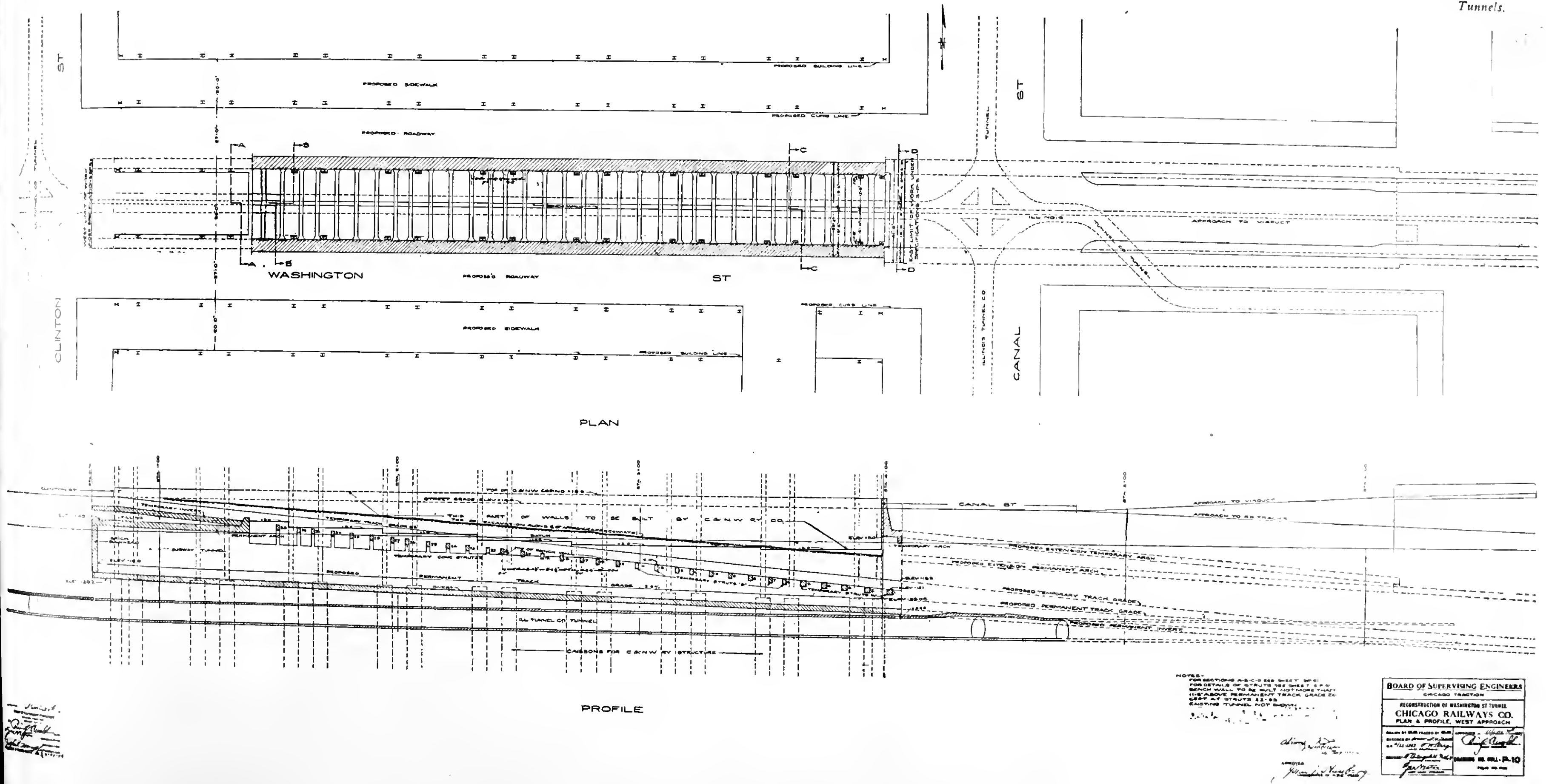
Western Society of Engineers
Vol. XVI. No. 9. Nov., 1911
Artingstall—Chicago River Tunnels.



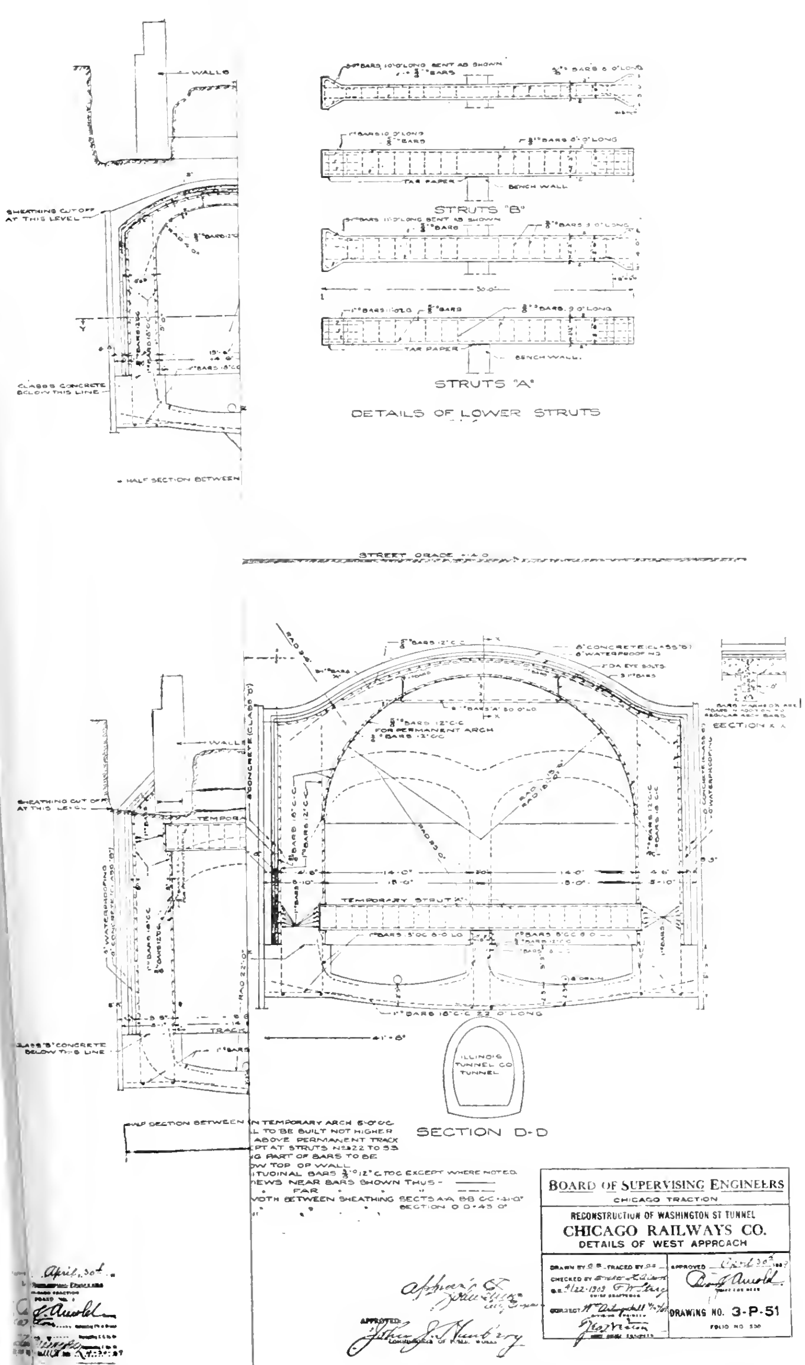
Washington Street Tunnel. Fig. 5.


APPROACH TO VIADUCT
TUNNEL CO. TUNNEL
STA 5+00
APPROACH TO VIADUCT
APPROACH TO R.R. TRACKS
TEMPORARY ARCH
ARCH
TRACK GRADE
T TRACK GRADE
POSED PERMANENT INVERT
NOTES-
FOR SECTIONS A-B-C-D SEE SHEET 3P-51
FOR DETAILS OF STRUTS SEE SHEET 3 P-51
BENCH WALL TO BE BUILT NOT MORE THAN 11-8" ABOVE PERMANENT TRACK GRADE, EXCEPT AT STRUTS 22-63
EXISTING TUNNEL NOT SHOWN
APPROVED
COMMISSIONER OF PUBLIC WORKS
BOARD OF SUPERVISING ENGINEERS
CHICAGO TRACTION
RECONSTRUCTION OF WASHINGTON ST TUNNEL
CHICAGO RAILWAYS CO.
PLAN & PROFILE, WEST APPROACH
DRAWN BY G.S. TRACED BY G.S.
CHECKED BY
O.K. 4/22-1909
CHIEF DRAFTSMAN
CORRECT
DIVISION ENGINEER
ASST CHIEF ENGINEER
APPROVED
DRAWING NO. ROLL - P-10
FOLIO NO

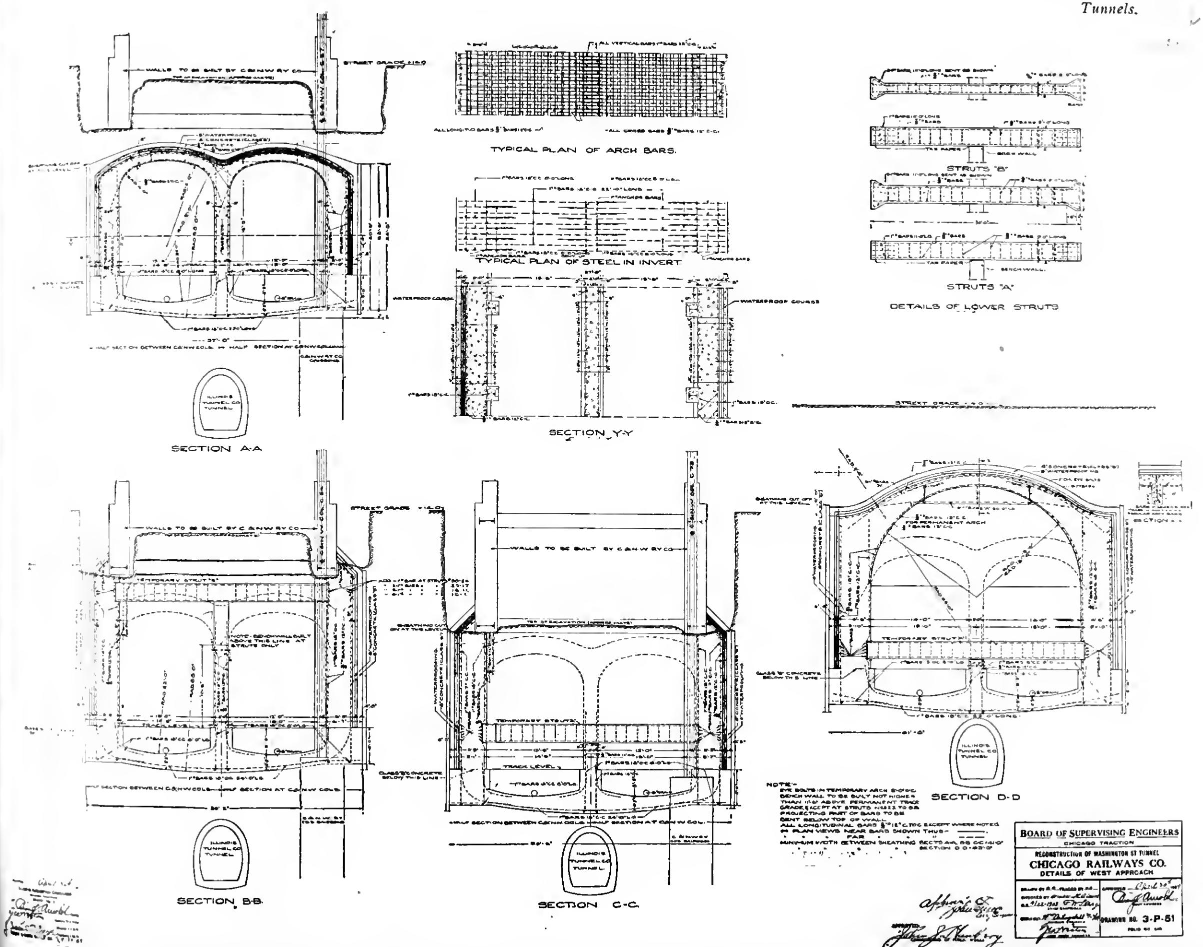
Washington Street Tunnel. Fig. 14.


CLINTON ST
WASHINGTON ST
CANAL ST
PROPOSED SIDEWALK
PROPOSED ROADWAY
PROPOSED BUILDING LINE
PROPOSED CURB LINE
ILLINOIS TUNNEL CO
TUNNEL
APPROACH TO VIADUCT
WEST LIMIT OF WORK
EAST LIMIT OF WORK UNDER SPECIFICATIONS
A
B
C
D
PLAN
TOP OF C&NW COPING
STREET GRADE
THIS PART OF WALLS TO BE BUILT BY C&NW RY CO.
TOP OF EXCAVATION ALONG ⊄ OF APPROACH (APPROXIMATE)
TEMPORARY INVERT
FILLING
TEMPORARY TRACK GRADE
PERMANENT ARCH
BRICK BULKHEAD
SUBWAY TUNNEL
TEMPORARY CONC STRUTS
TOP OF BENCH WALL
TEMPORARY STRUTS
PROPOSED PERMANENT TRACK GRADE
INVERT
ILL TUNNEL CO TUNNEL
CAISSONS FOR C&NW RY STRUCTURE
CANAL ST
APPROACH TO VIADUCT
APPROACH TO RR TRACKS
TEMPORARY ARCH
PROPOSED EXTENSION TEMPORARY ARCH
PROPOSED EXTENSION PERMANENT ARCH
PROPOSED TEMPORARY TRACK GRADE
PROPOSED PERMANENT TRACK GRADE
PROPOSED PERMANENT INVERT
PROFILE
NOTES:-
FOR SECTIONS A-B-C-D SEE SHEET
FOR DETAILS OF STRUTS SEE SHEET
BENCH WALL TO BE BUILT NOT MORE THAN 11-6" ABOVE PERMANENT TRACK GRADE EXCEPT AT STRUTS
EXISTING TUNNEL NOT SHOWN
APPROVED
BOARD OF SUPERVISING ENGINEERS
CHICAGO TRACTION
RECONSTRUCTION OF WASHINGTON ST TUNNEL
CHICAGO RAILWAYS CO.
PLAN & PROFILE, WEST APPROACH
DRAWING NO.

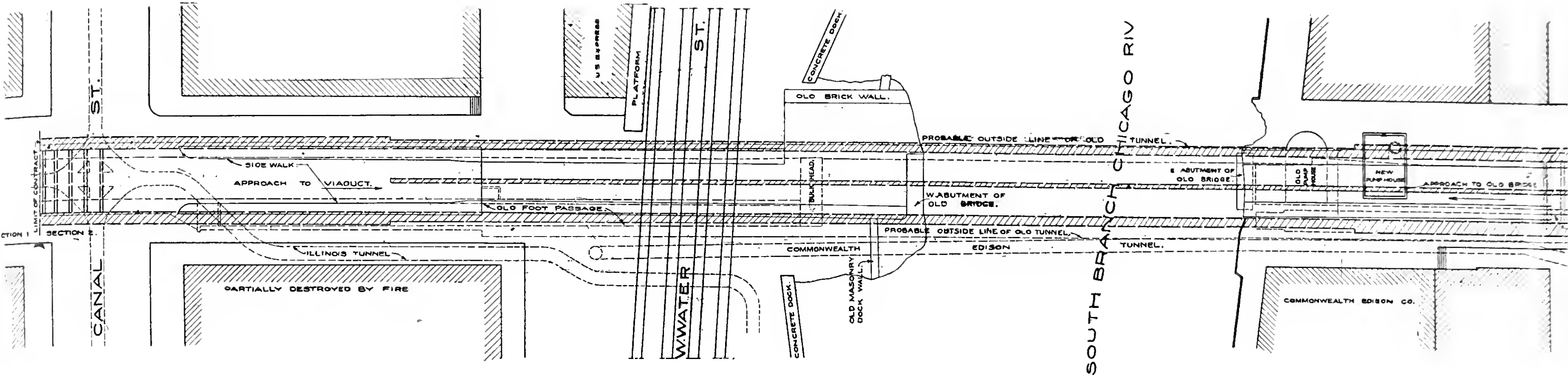
Washington Street Tunnel. Fig. 14.



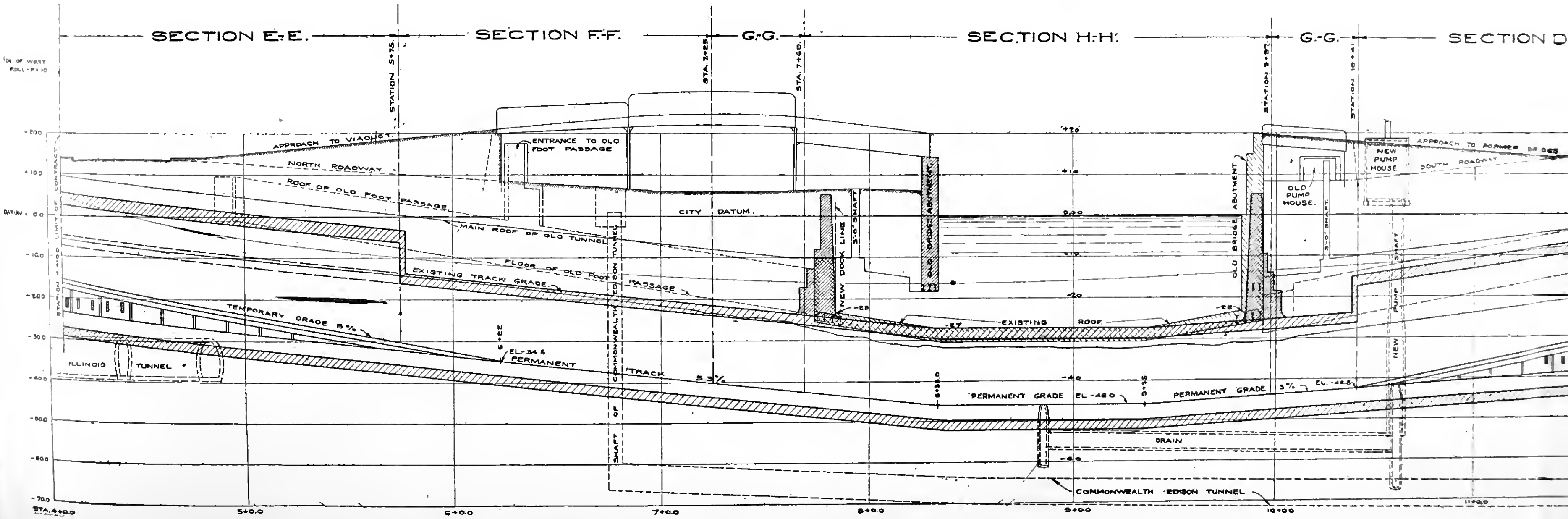
Washington Street Tunnel. Fig. 15.

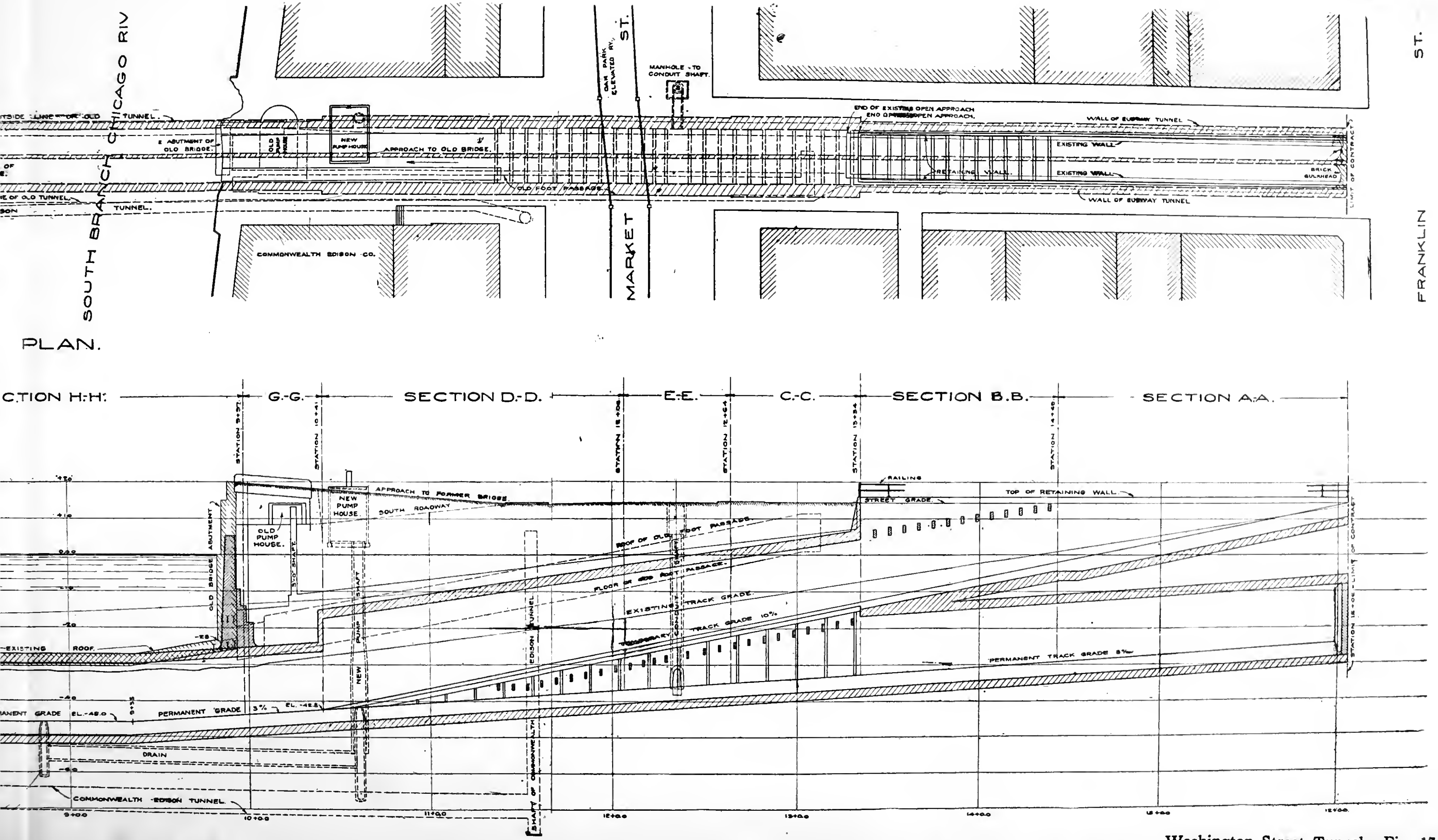

WALLS TO BE BUILT BY C. & N. W. RY. CO.
STREET GRADE
TYPICAL PLAN OF ARCH BARS.
TYPICAL PLAN OF STEEL IN INVERT
WATERPROOF COURSE
SECTION Y-Y
STRUTS "B"
STRUTS "A"
DETAILS OF LOWER STRUTS
STREET GRADE
ILLINOIS TUNNEL CO. TUNNEL
SECTION A-A
TEMPORARY STRUT
NOTE: BENCH WALL BUILT ABOVE THIS LINE AT STRUTS ONLY
TRACK LEVEL
HALF SECTION BETWEEN C. & N. W. COLS. / HALF SECTION AT C. & N. W. COLS.
SECTION B-B
SECTION C-C
SECTION D-D
NOTE:-
EYE BOLTS IN TEMPORARY ARCH 5'-0" C.C.
BENCH WALL TO BE BUILT NOT HIGHER THAN 11'-6" ABOVE PERMANENT TRACK GRADE EXCEPT AT STRUTS
PROJECTING PART OF BARS TO BE BENT BELOW TOP OF WALL
ALL LONGITUDINAL BARS ⅝" 12" C. TO C. EXCEPT WHERE NOTED
IN PLAN VIEWS NEAR BARS SHOWN THUS
FAR
MINIMUM WIDTH BETWEEN SHEATHING
BOARD OF SUPERVISING ENGINEERS
CHICAGO TRACTION
RECONSTRUCTION OF WASHINGTON ST TUNNEL
CHICAGO RAILWAYS CO.
DETAILS OF WEST APPROACH
DRAWING NO. 3-P-51

Washington Street Tunnel. Fig. 15.

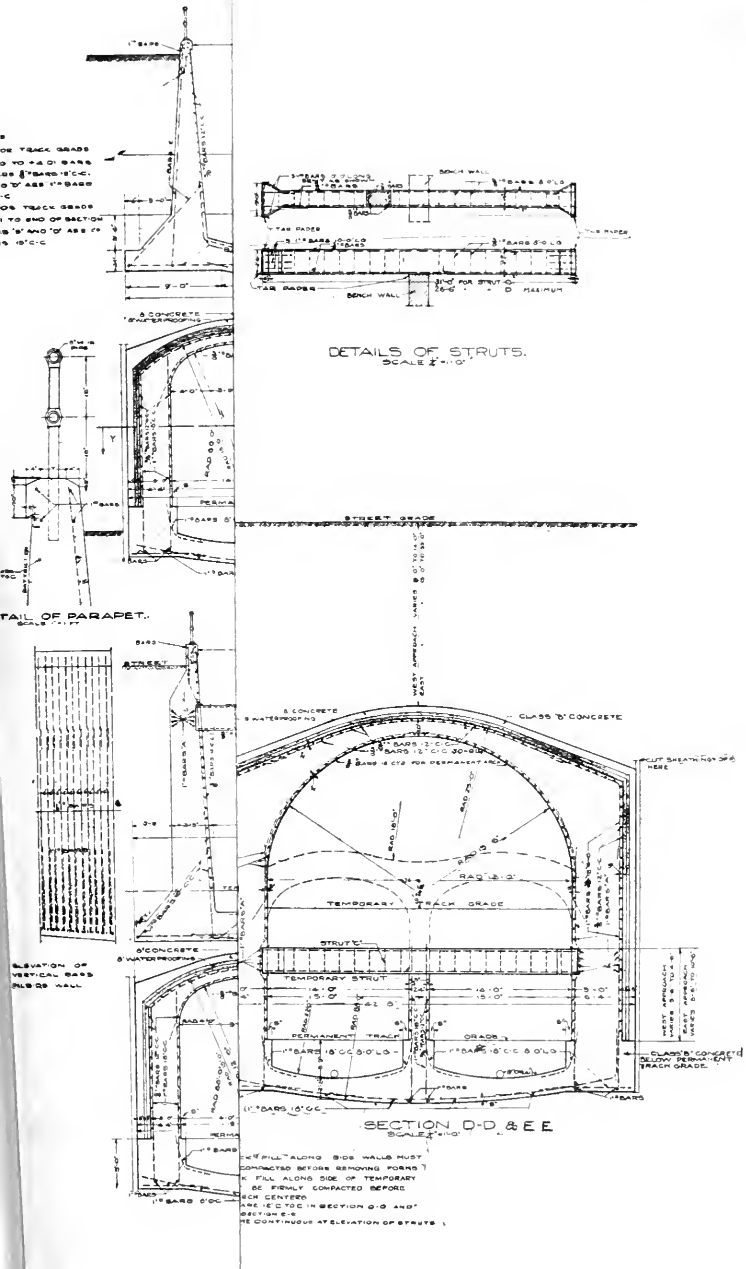

CANAL ST.
W. WATER ST.
SOUTH BRANCH CHICAGO RIV
U S EXPRESS
PLATFORM
CONCRETE DOCK
OLD BRICK WALL
PROBABLE OUTSIDE LINE OF OLD TUNNEL
SIDE WALK
APPROACH TO VIADUCT
OLD FOOT PASSAGE
BULK HEAD
W. ABUTMENT OF OLD BRIDGE
E. ABUTMENT OF OLD BRIDGE
OLD PUMP HOUSE
NEW PUMP HOUSE
APPROACH TO OLD BRIDGE
LIMIT OF CONTRACT
SECTION 1
SECTION 2
ILLINOIS TUNNEL
COMMONWEALTH EDISON TUNNEL
PROBABLE OUTSIDE LINE OF OLD TUNNEL
PARTIALLY DESTROYED BY FIRE
OLD MASONRY DOCK WALL
CONCRETE DOCK
COMMONWEALTH EDISON CO.

PLAN.

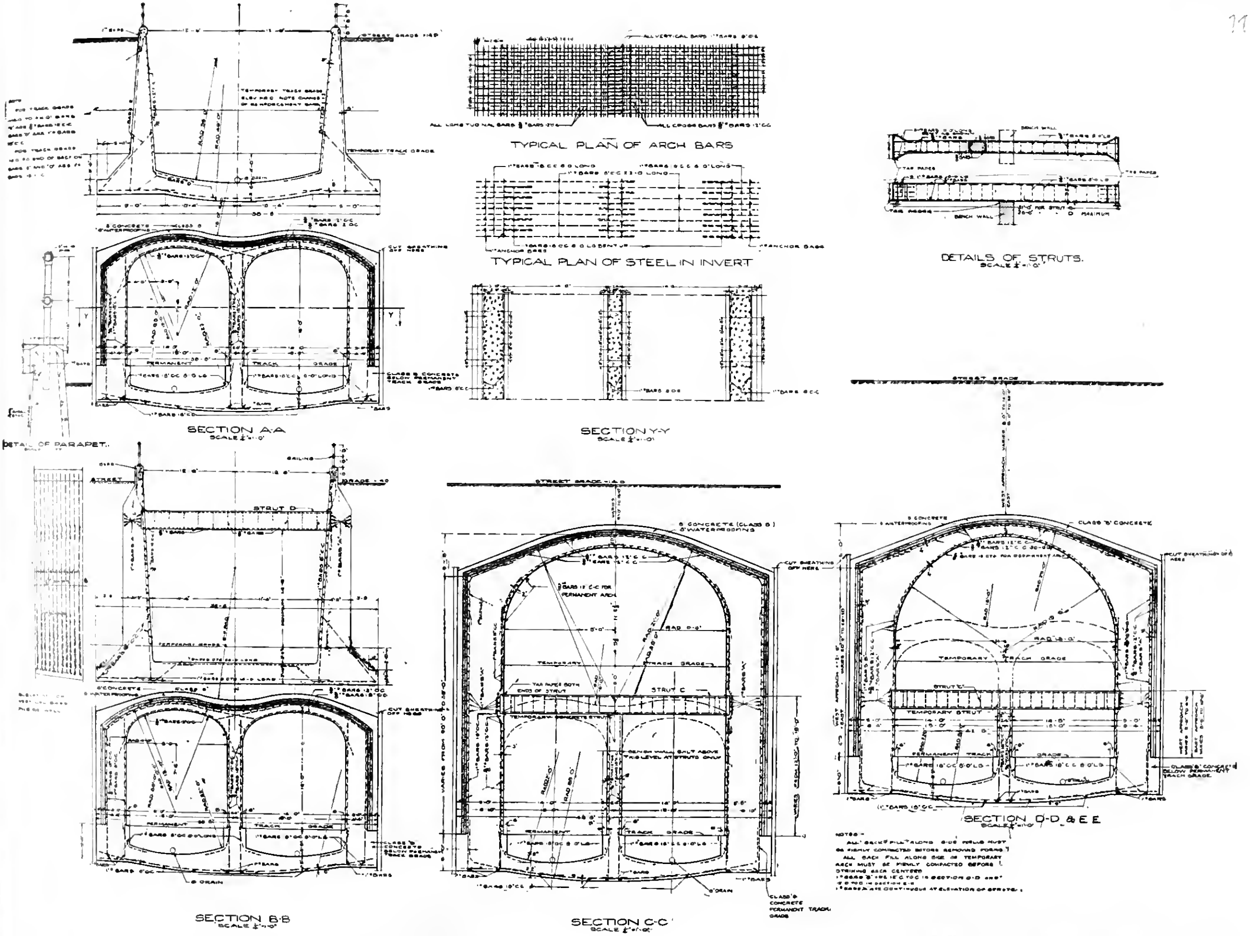

SECTION E-E.
SECTION F-F.
G-G.
SECTION H-H.
G-G.
SECTION D
STATION 5+75
STA. 7+25
STA. 7+60
STATION 9+97
STATION 10+41
APPROACH TO VIADUCT
ENTRANCE TO OLD FOOT PASSAGE
NORTH ROADWAY
ROOF OF OLD FOOT PASSAGE
CITY DATUM
MAIN ROOF OF OLD TUNNEL
FLOOR OF OLD FOOT PASSAGE
EXISTING TRACK GRADE
TEMPORARY GRADE 5%
EL-34.8 PERMANENT TRACK 5.3%
SHAFT OF COMMONWEALTH EDISON TUNNEL
NEW DOCK LINE
5'-0" SHAFT
OLD BRIDGE ABUTMENT
OLD BRIDGE ABUTMENT
EXISTING ROOF
PERMANENT GRADE EL-46.0
PERMANENT GRADE 3%
EL-42.8
OLD PUMP HOUSE
5'-0" SHAFT
NEW PUMP HOUSE
NEW PUMP SHAFT
APPROACH TO FORMER BRIDGE
SOUTH ROADWAY
DRAIN
COMMONWEALTH EDISON TUNNEL
ILLINOIS TUNNEL
STATION 4+00 LIMIT OF CONTRACT
DATUM 0.0
+20.0
+10.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
STA. 4+0.0
5+0.0
6+0.0
7+0.0
8+0.0
9+0.0
10+00
11+0.0



Washington Street Tunnel. Fig. 17.


DETAILS OF STRUTS.
SCALE ¼"=1'-0"
BENCH WALL
TAR PAPER
31'-0" FOR STRUT C
26'-6" " " D MAXIMUM
STREET GRADE
TAIL OF PARAPET.
ELEVATION OF VERTICAL BARS
6" CONCRETE
6" WATERPROOFING
CLASS "B" CONCRETE
CUT SHEATHING OFF HERE
RAD. 18'-0"
RAD. 13'-0"
TEMPORARY TRACK GRADE
STRUT "C"
TEMPORARY STRUT
PERMANENT TRACK GRADE
WEST APPROACH VARIES 3'-6" TO 4'-6"
EAST APPROACH VARIES 5'-6" TO 10'-0"
CLASS "B" CONCRETE BELOW PERMANENT TRACK GRADE
SECTION D-D & E-E
SCALE ¼"=1'-0"
FILL ALONG SIDE WALLS MUST BE COMPACTED BEFORE REMOVING FORMS
FILL ALONG SIDE OF TEMPORARY BE FIRMLY COMPACTED BEFORE ARCH CENTERS
ARE 12" C TO C IN SECTION D-D AND SECTION E-E
ARE CONTINUOUS AT ELEVATION OF STRUTS

Washington Street Tunnel. Fig. 18.



Washington Street Tunnel. Fig. 18.

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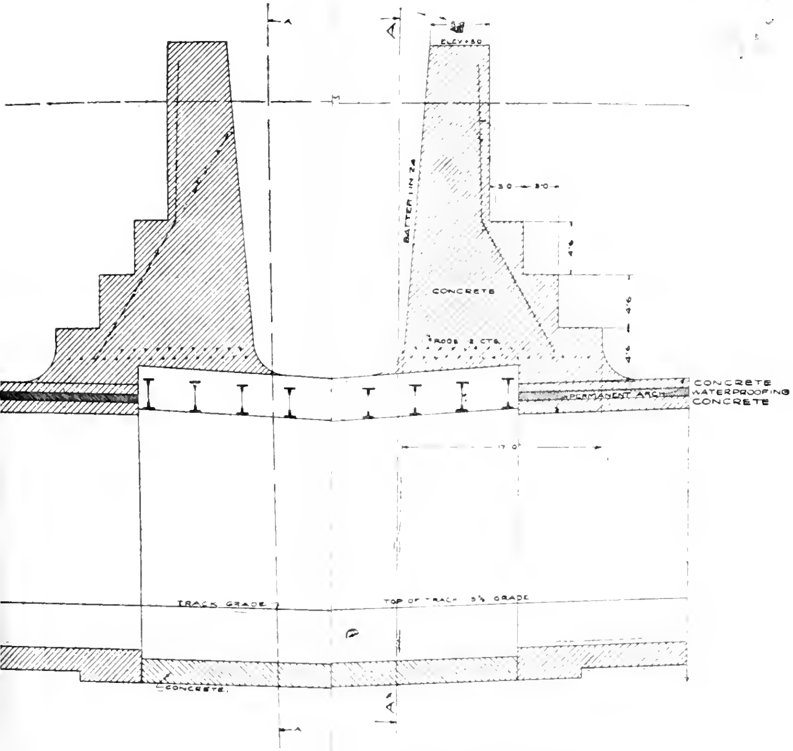
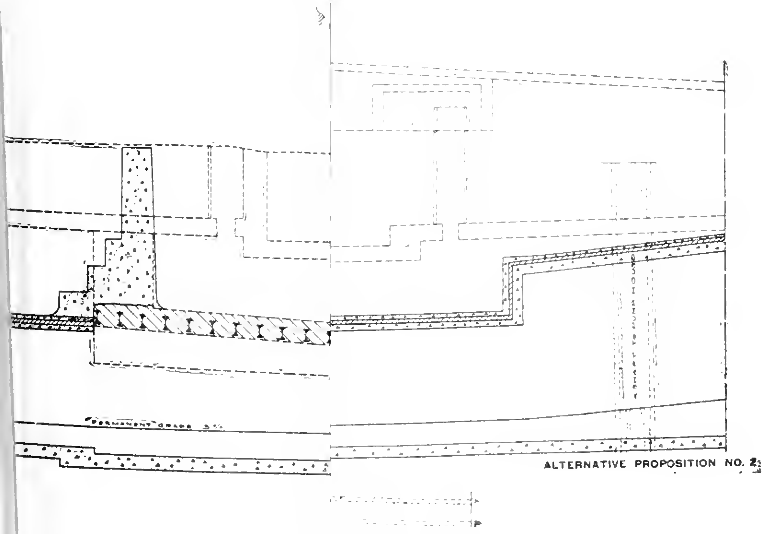
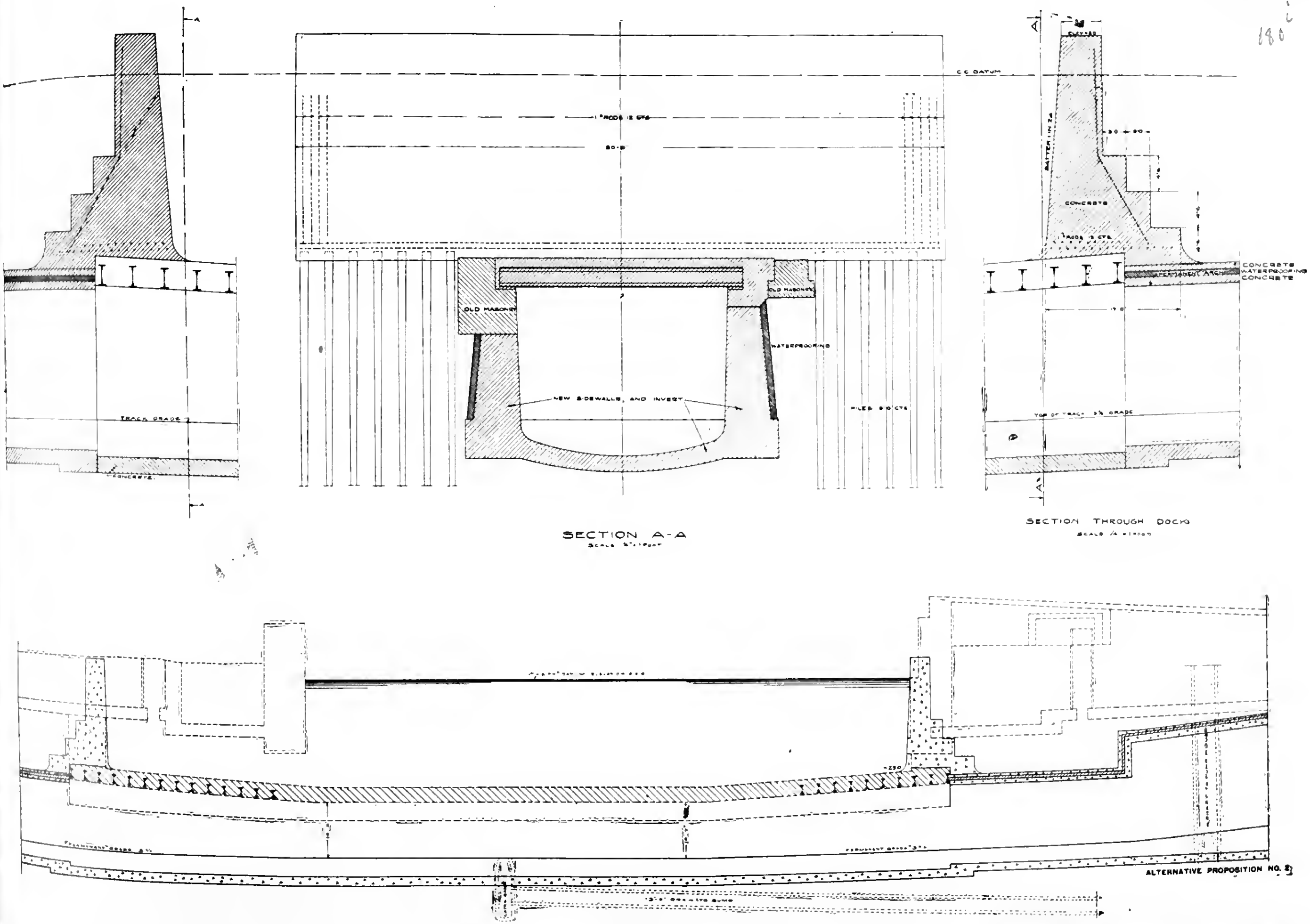


SECTION THROUGH DOCK
SCALE 1/4 = 1 FOOT

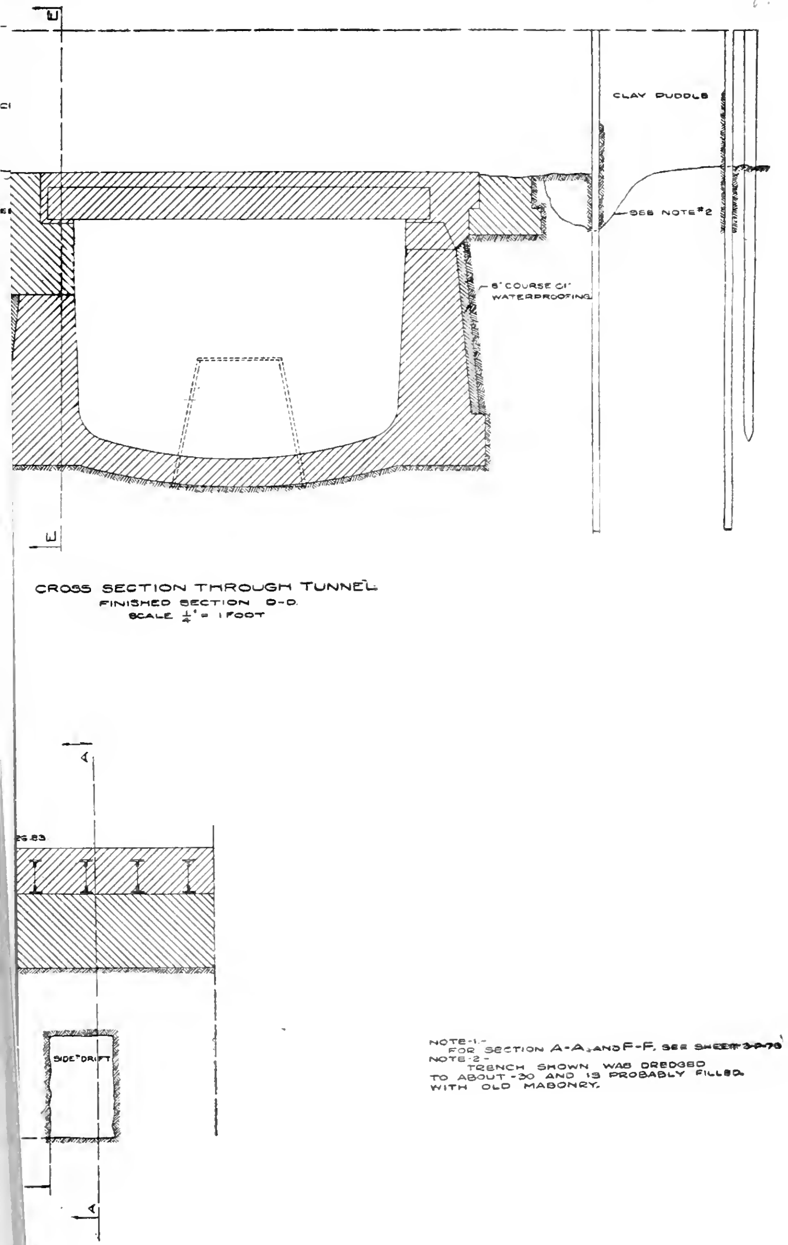


ALTERNATIVE PROPOSITION NO. 2

Washington Street Tunnel. Fig. 19.



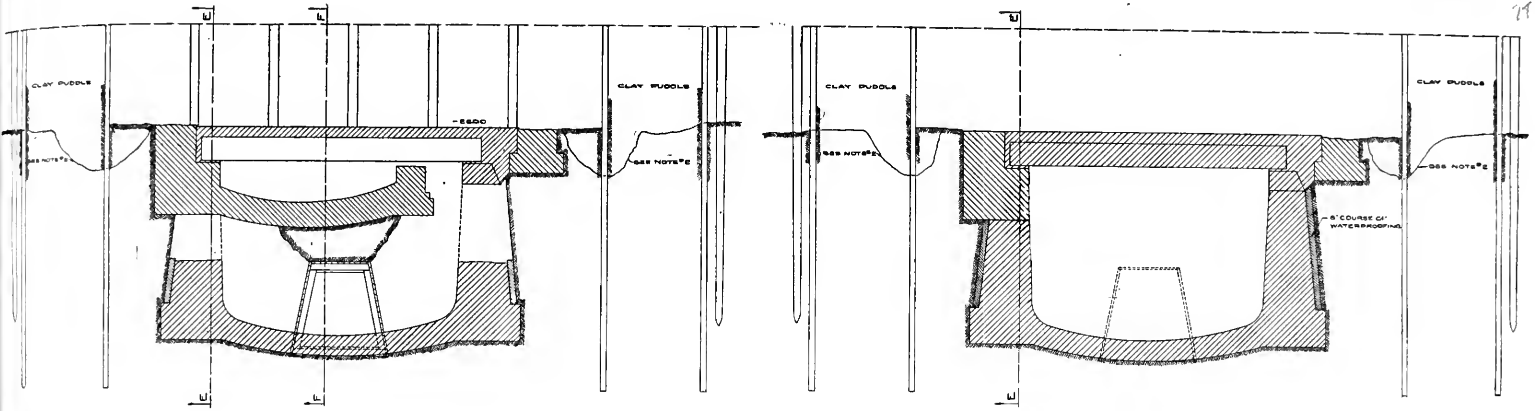
Washington Street Tunnel. Fig. 19.



CROSS SECTION THROUGH TUNNEL
FINISHED SECTION D-D.
SCALE 1/4" = 1 FOOT

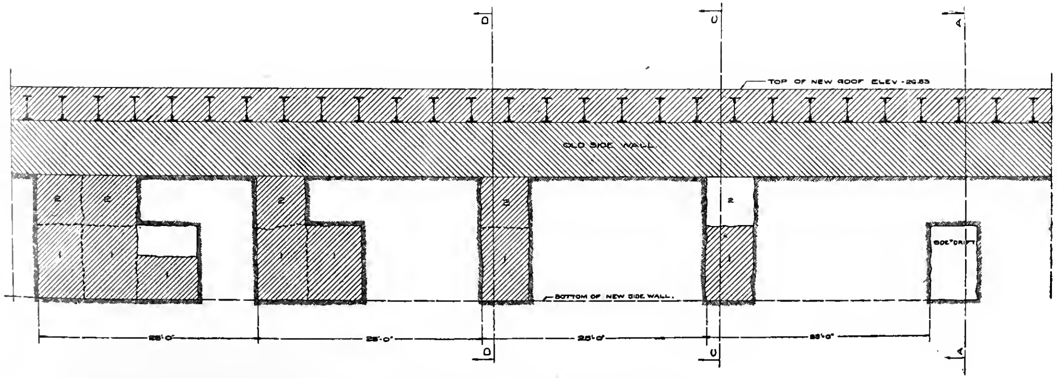
NOTE-1.-
FOR SECTION A-A, AND F-F, SEE SHEET 3-P-70
NOTE-2-
TRENCH SHOWN WAS DREDGED TO ABOUT -30 AND IS PROBABLY FILLED WITH OLD MASONRY.

Washington Street Tunnel. Fig. 20.



CROSS SECTION C-C THROUGH TUNNEL,
SCALE ¼" = 1 FOOT.

CROSS SECTION THROUGH TUNNEL
FINISHED SECTION D-D.
SCALE ¼" = 1 FOOT



LONGITUDINAL SECTION THROUGH SIDEWALL.
SHOWING METHOD OF DRIFTING,
SECTION E-E.
SCALE ¼" = 1 FOOT.

NOTE-1:-
FOR SECTION A-A, AND F-F, SEE [illegible]
NOTE-2-
TRENCH SHOWN WAS DREDGED TO ABOUT -30 AND IS PROBABLY FILLED WITH OLD MASONRY.

Washington Street Tunnel. Fig. 20.

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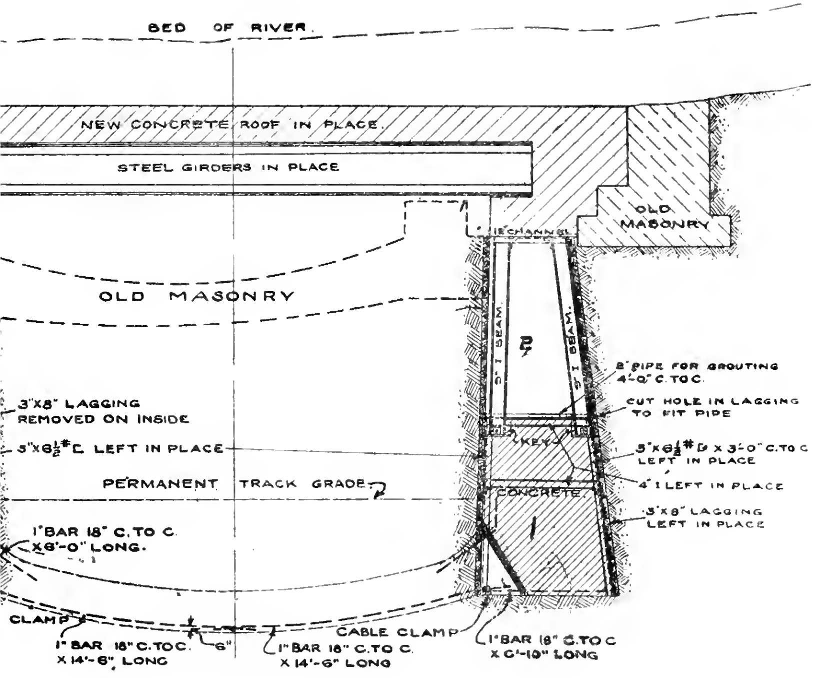
BED OF RIVER.
NEW CONCRETE ROOF IN PLACE.
STEEL GIRDERS IN PLACE
OLD MASONRY
12" CHANNEL
OLD MASONRY
5" I BEAM.
5" I BEAM.
8" PIPE FOR GROUTING 4'-0" C. TO C.
CUT HOLE IN LAGGING TO FIT PIPE
3"X8" LAGGING REMOVED ON INSIDE
5"X6½#C LEFT IN PLACE
KEY
5"X6½#C X 3'-0" C. TO C LEFT IN PLACE
4" I LEFT IN PLACE
PERMANENT TRACK GRADE
CONCRETE
3"X8" LAGGING LEFT IN PLACE
1" BAR 18" C. TO C. X6'-0" LONG.
CLAMP
1" BAR 18" C. TO C. X 14'-6" LONG
6"
1" BAR 18" C. TO C. X 14'-6" LONG
CABLE CLAMP
1" BAR 18" C. TO C X 6'-10" LONG

SECTION "G-G."

Washington Street Tunnel. Fig. 21

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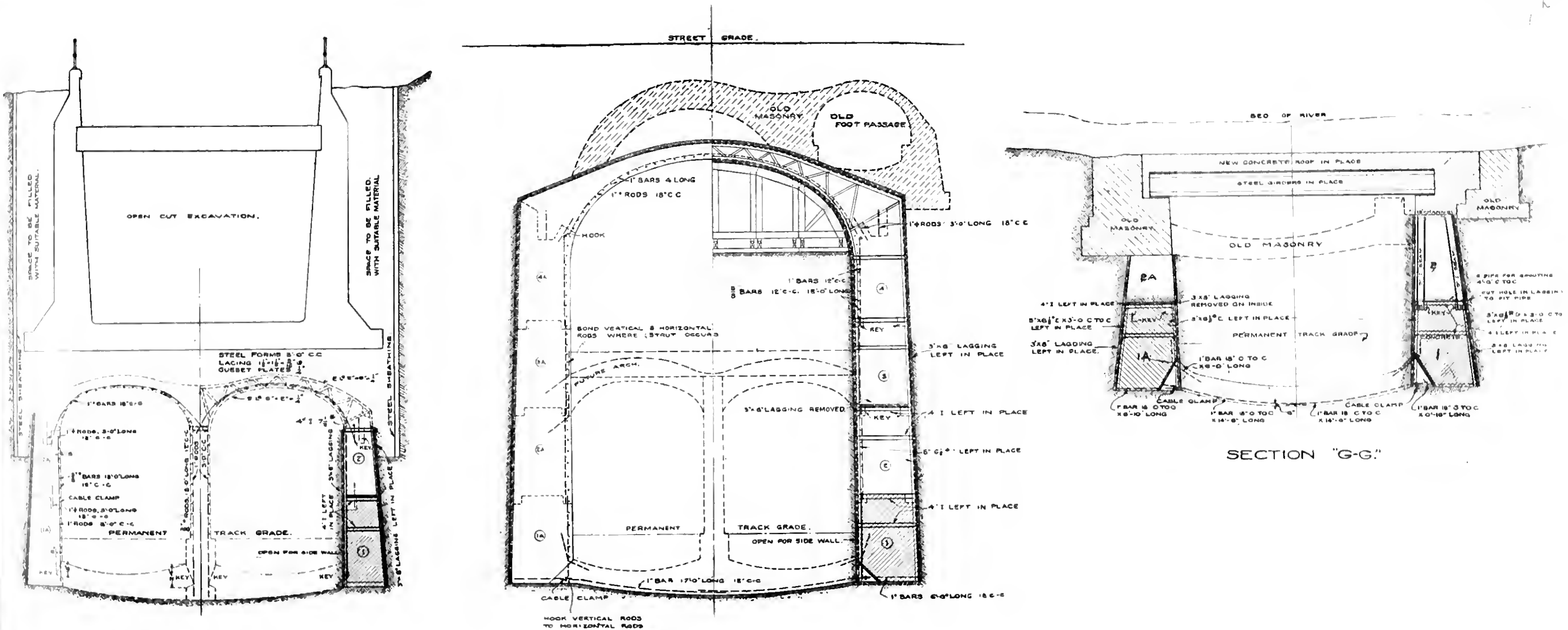
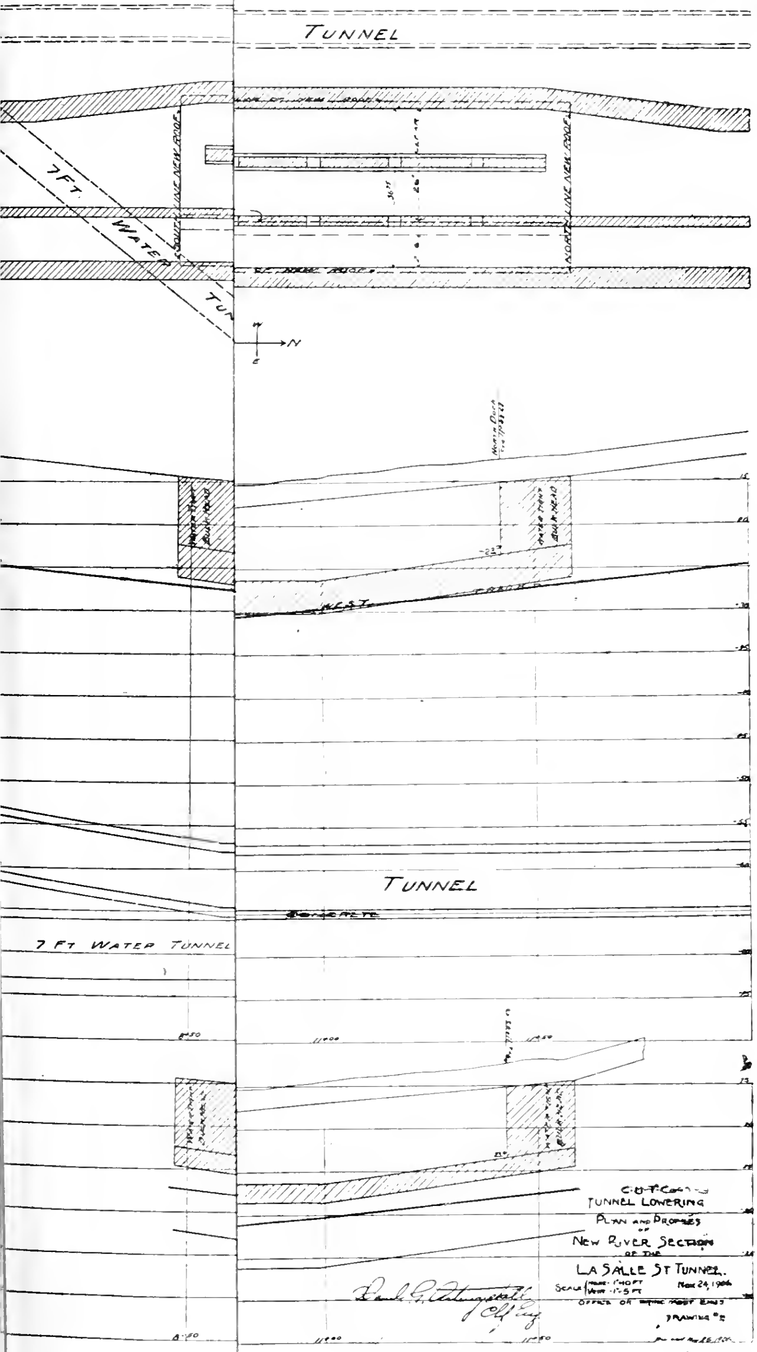


SECTION "AA & BB."

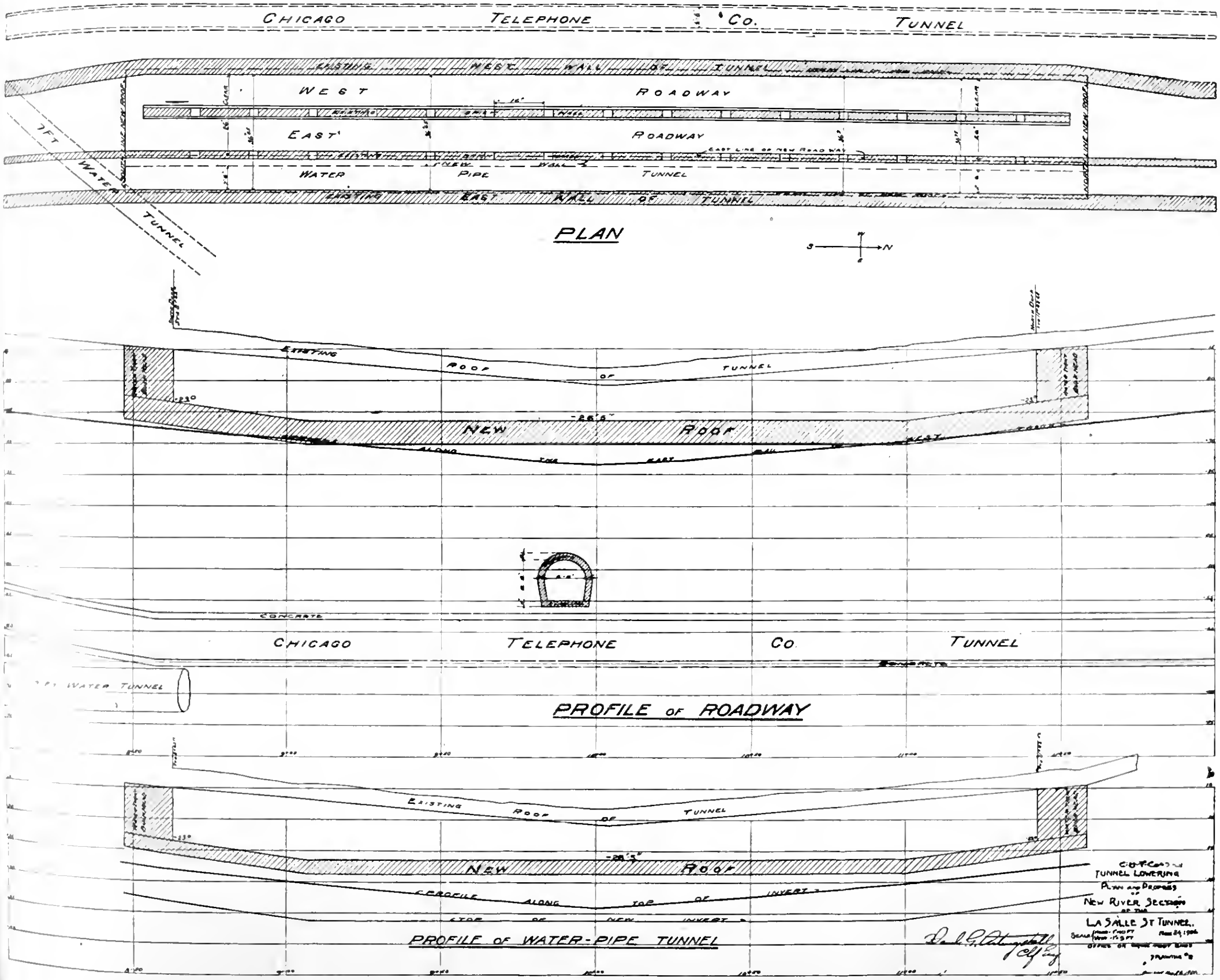
SECTION "C-C."

SECTION "G-G."

Washington Street Tunnel. Fig. 21



La Salle Street Tunnel. Fig. 22.



La Salle Street Tunnel. Fig. 22.

the screw. One set of the shoring was placed about 3 ft. from each wall and consisted of four drums and jacks to a series, each series 3 ft. centers. The top and bottom blocks were 12 in. by 12 in. timbers. This left a clear space 10 ft. wide down the center of the main tunnel.

The specifications provided that "seats for girders shall be cut in the north wall and the masonry prepared for the bed plates of girders," and, in accordance with this clause, there had been cut in this wall chases sufficiently large to admit the girders and leave ample space for concrete and waterproofing (Fig. 7). The girders had been set (Fig. 8) accordingly and preparations made for placing the roof concrete, when a request, made by the City, that the intermediate piers be cut out, necessitated the cutting away of all the brickwork in the north wall as far back as the end of the new girders and about 2 ft. above the top flange. This left the wall overhanging the new girders about 3 ft. and carrying the old roof beams on the overhang. These old girders carried a load of about 75,000 lb., or approximately $4\frac{1}{4}$ tons per sq. ft. of wall, and involved very careful shoring and continual watching. The brickwork was considerably eroded by frost and ice, and in consequence, great care had to be exercised in cutting it away. Only those piers between pairs of girders widely separated were cut out at any one time, and the concrete for the new roof was then placed as quickly as possible. This was allowed to set for not less than seven days before the adjoining masonry was disturbed. Following this method of pro-

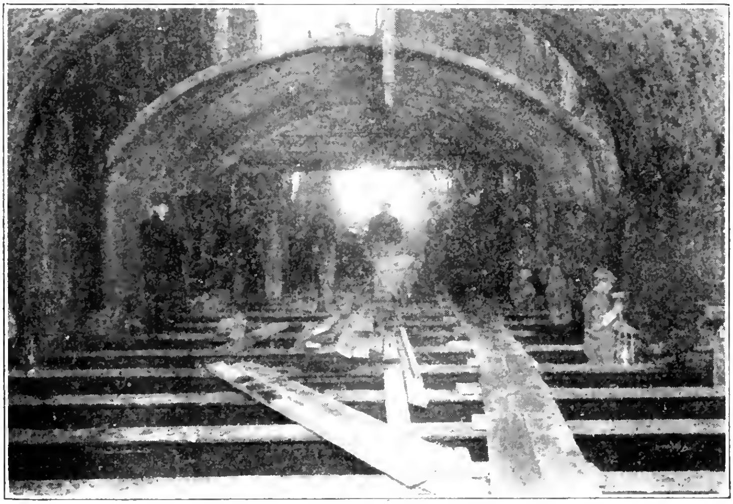


Fig. 8

cedure, the walls were slowly blocked and wedged up until finally the whole wall was carried on blocking, resting directly on the new concrete, with part of the roof load carried by the shoring.

When the concrete for the entire length of the new roof had been placed, the waterproofing was laid down the center and at such other places of the new roof as were not occupied by blocks or shoring.

The waterproofing was mixed and boiled at the street level and lowered in buckets down a shaft located near the east end of the work. The mastic used consisted of asphalt, asphalt cement and marble dust, the amount of any one being governed by the requirements of the particular location or condition. In general, however, the asphalt was about 50 per cent of the total mixture. An inch layer of the mixture was spread on the roof and hard sewer-brick was immediately imbedded therein .with joints not less than ½ in., which were then flooded with a thinner mixture of the same mastic.

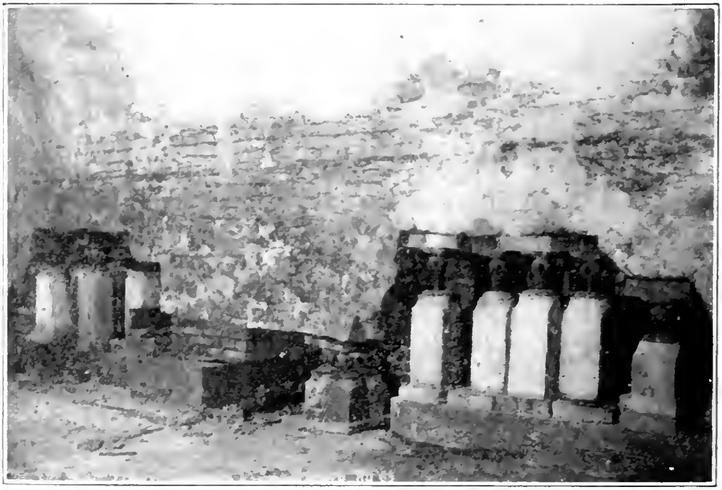


Fig. 9

Considerable difficulty was experienced in placing the waterproofing under and along the walls, on account of the shoring and blocking (Figs. 9, 10, 11, 12). Not more than 4 or 5 square feet could be obtained at any one place between the blocking, but this space was waterproofed and the concrete cover placed. The following day the wall was underpinned with brick laid in Portland cement with the last course of brick tightly driven home. After a week or ten days, the blocking adjacent to this underpinning was removed and this portion similarly waterproofed and the wall underpinned. Continuing this method, the full length of 220 ft. was underpinned and the space between the old and new roofs filled to a depth of 5 or 6 feet with clay, brickbats and other debris to act as a cushion and prevent injury to the new work during the removal of the old

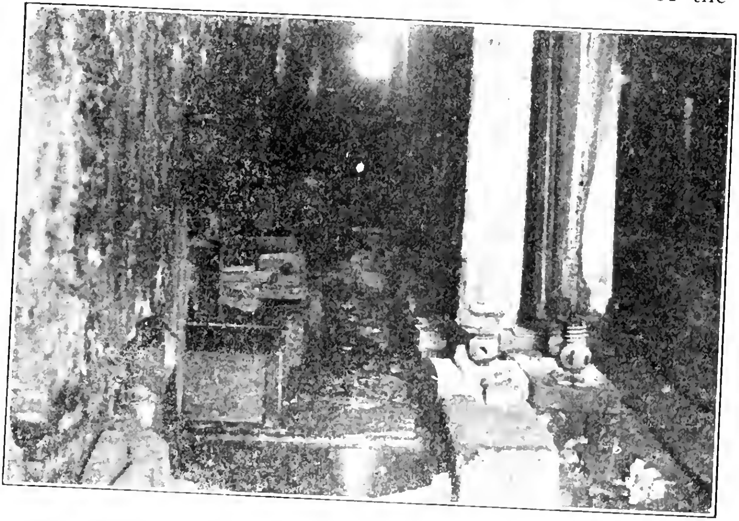


Fig. 10

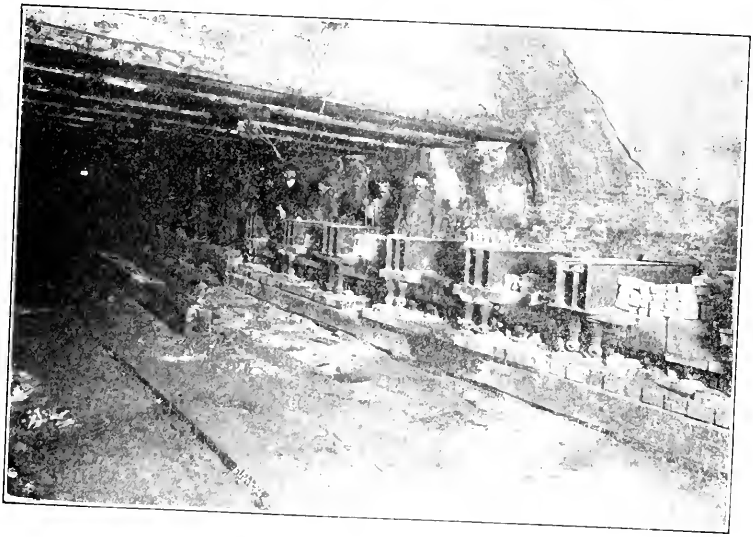


Fig. 11

roof. The walls above the new roof were then weakened by cutting vertical chases about 2 ft. wide with a depth of 2 ft. and 4 or 5 ft. apart (Fig. 13).

While this was being done, the bulkheads at either end were being built. These were constructed of brick firmly bonded to the old arch and extended a foot below the top flange of the new girders. The east bulkhead was built under the east abutment of the old bridge, but the west bulkhead was built about 50 ft. west of the present dock line. The former was closed up at once, but, through the latter, a 3 by 4 ft. opening was left and fitted with a heavy, watertight gate which could be easily closed in case of emergency. This opening provided a means of ingress and egress for the men who were engaged in weakening the walls as above stated. The old roof and walls at the junction of the east bulkhead were then drilled with holes 6 in. apart and extending the full thickness of the brickwork. This allowed the separation of the bulkhead and remaining masonry from the portion which extended out under the river. The holes were plugged as soon as drilled. The brickwork at the end of the old girders was then cut away, and the opening in the west bulkhead bricked up on May 29, 1907.

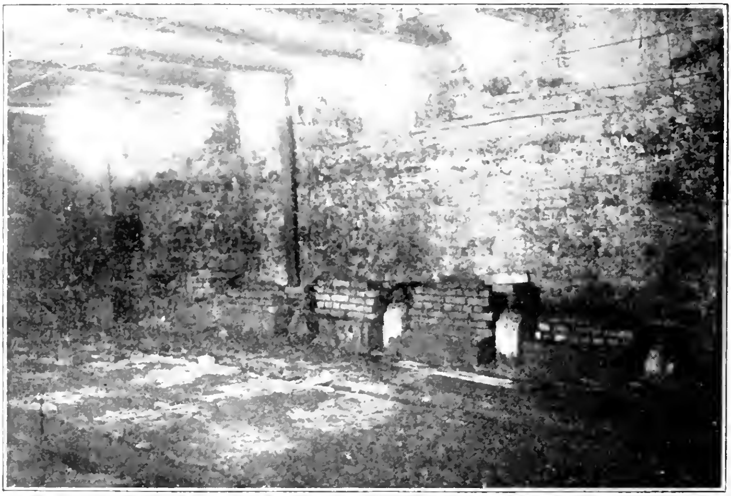


Fig. 12

The center pier masonry was removed by a derrick and the timber crib and substructure removed by means of a dredge.

Removal of the Roof and Walls:

A trench was first dredged to about 30 ft. Chicago City Datum along the walls, and part of the old center pier protection removed. A 12-inch I-beam was then set on the old roof close to the east dock and, by means of a pile driver, broke down, piece by piece, the full length of the jack arch between two girders.

These jack arches were very solid and only small pieces would break off at each setting. In fact nearly two-thirds of the time the I-beam would merely cut its way through the brickwork, so, practically every foot of the jack arch had to be cut through. This process was repeated for six or seven jack arches, and then a heavy chain would be fastened around one end of a girder by a diver and brought to a pair of heavy steel 5-sheave pulley blocks which were fastened to the leads on the pile driver. The free end of the cable was lead to the hoisting drum and a strain put on the cable. Sometimes a beam would be freed in five or ten minutes, but more frequently a couple of hours' pull was required before the beam was loosened and brought to the surface. About three beams pulled was an average day's work. Another difficulty encountered in breaking down the jack arches was the slewing around of the I-beam under the first blow or two of the hammer and one end striking a flange of the girder; but, as it took less time to drive the I-beam through the flange than to free it from the superincumbent concrete, we kept on hammering until through.

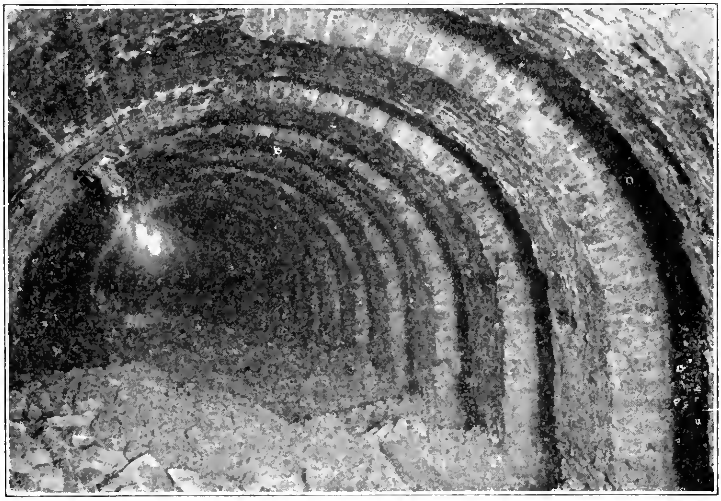


Fig. 13

The center-pier masonry below the old crib, the walls of the tunnel, and brick roof of the foot passage had been weakened so thoroughly that no difficulty was encountered in dredging them down to the required depth.

There was but one accident during the progress of the work, when a section of brickwork fell on one of the laborers and crushed his legs. He was in the hospital nearly a year, and, from last reports, he has not yet recovered the use of these members.

November, 1911

The contractor's superintendent on this work was Mr. Paul Weuster, a careful, conscientious man, whose method of handling the work, especially the shoring, excited the admiration of the many engineers who visited the work.

RECONSTRUCTION IN 1909.

Under ordinances granted by the City Council on February 11, 1907, to the Chicago City Railway Company and to the Chicago Railways Company (successor to the Chicago Union Traction Company) the responsibility for the engineering for the reconstruction of the entire traction systems of the above companies, including the three tunnels described, was placed in a Board known as the "Board of Supervising Engineers, Chicago Traction." This Board consisted of Bion J. Arnold, chairman and chief engineer of the work; George Weston, representing the City of Chicago; John Z. Murphy, representing the Chicago Railways Company, and Harvey B. Fleming, representing the Chicago City Railway Company, each representative of the railway companies acting on this board for his respective company. When this board took up the reconstruction of the tunnels in 1909, a division known as the Division of Tunnels was established by the chief engineer of the work, and the writer was placed in charge of this division.

The reconstructed Washington Street Tunnel was divided into two sections: Section 1, lying west of Canal Street, and Section 2 extending from Canal Street on the west to Franklin Street on the east. The same conditions governed the design of this tunnel as governed the design of the La Salle Street Tunnel.

"The tunnel was so designed that it can be ultimately the connection between the territory west of the river and a subway in the business district."

"The tunnel is to be used temporarily by cars coming to the surface at either end of the tunnel."

"The street over and along the tunnel must be maintained for vehicular traffic."

"There must be a minimum interference with car traffic during the change from the surface to subway operation.

The design was treated similarly to that of the La Salle Street Tunnel. The permanent double-bore tunnel was built whenever possible, and the temporary track carried down through an open approach, the side walls of which will form the side walls of the finished subway tunnel. The open approach is constructed only as far as necessary before entering a single-bore tunnel which spans both tracks, with the outer walls of the permanent tunnel extended up to form the walls of the single-bore tunnel. In order to economize material, these high walls have concrete struts extending across the tunnel just below the temporary track grade. These struts take the side thrust of the walls at about one-third the height above the foundations, and also carry the temporary (present) street car tracks.

Section 1:

This section of the tunnel lying between Clinton and Canal streets, consists of about 70 lineal feet of double-bore reinforced-concrete tunnel at the Clinton Street end of the contract, and 330 lineal feet of temporary open approach which extends easterly to Canal Street, where there is constructed a short section (10 feet) of single-bore arch (Figs. 14 and 15). Located between these two streets is the new terminal station of the Chicago & Northwestern Railway, the plans of which being prepared early in 1909, provided for carrying the train sheds over the site of the old tunnel approach, and, as both the C. & N. W. Ry., and the street railway company had work which could be carried on more advantageously by the two companies working together, it was deemed advisable to prosecute the reconstruction of this section of tunnel, at or about the time that the C. & N. W. Ry. Co. were sinking the caissons to carry their tracks over Washington Street.

After several conferences between the Board of Supervising Engineers and the C. & N. W. Ry. Company's engineer, an agreement was entered into between the C. & N. W. Ry. Co. on the one hand, and the Chicago Railways Company on the other hand, whereby the latter company was permitted to construct the west 410 ft., or Section 1 of the new tunnel, in conjunction with the work of the C. & N. W. Ry. Co.

Plans and specifications were immediately prepared, and in response to the advertisements, the following bids were received:

Geo. W. Jackson, Inc.	$ 81,874.50,	150 days to complete
M. H. McGovern Co.	107,689.80,	205 days to complete
Great Lakes Dredge & Dock Co. .	137,800.00,	150 days to complete
National Contracting Co.	140,045.00,	197 days to complete
Nash Bros.	166,587.00,	184 days to complete
Chief Engineer's Estimate	116,735.00,	180 days to complete

The contract was awarded to Geo. W. Jackson, Inc. Owing to a delay on the part of the C. & N. W. Ry. Co., the contractor was unable to begin actual work until late in August. Early in the month, however, the contractors began the erection of an overhead cableway, one tower of which was located at Clinton Street, and the other just east of Canal Street. A pile driver, sheathing, bracing, etc., were brought to the site of the work and preparations made for starting construction work on the tunnel.

On August 23rd the Chicago Railways Company received notice that the C. & N. W. Ry. Co. had completed their caissons and the former company then took possession of the site and authorized the contractor to proceed with the tunnel work. Steel sheet piling was driven for about the west half of the work, while the excavation and bracing followed as rapidly as possible.

As the Illinois Tunnel underlies the work, a shaft was sunk and connected with this tunnel about 200 ft. east of Clinton Street. The excavation was brought to this shaft either by the overhead cableway or by Kopple cars, dumped into cars of the Illinois Tunnel Company and hauled to a convenient location, where the material was dumped into scows and disposed of in the lake.

As will be seen by referring to Figs. 14 and 15, this section of the tunnel provides for a connection between the tunnel and a future subway, also for a temporary connection between the tunnel and the street surface. The length of the subway tunnel is governed by the grade of the temporary approach, only sufficient room being left above the arch at the easterly end of the subway tunnel to place ballast for the temporary track. Between this point and the permanent grade the temporary track is carried by a trestle on a descending grade of 9 per cent.

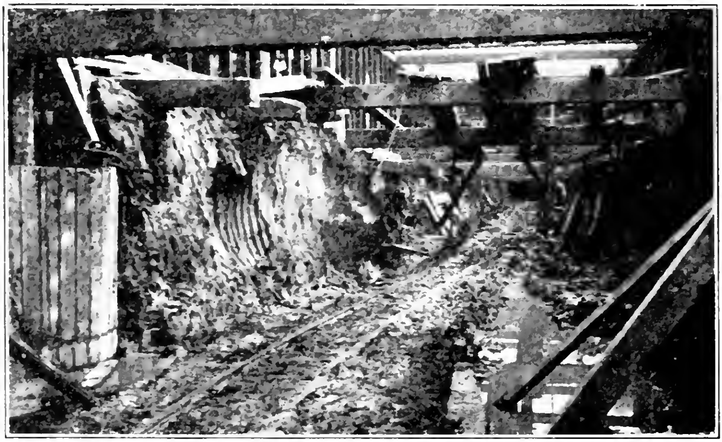


Fig. 16

Under the agreement with the C. & N. W. Ry. Co., the Chicago Railways Company was not obliged to build the side walls above a certain height, as provisions had been made by the former company to complete the walls to street grade and build the parapet wall around the tunnel.

While steel sheathing was being driven at the west end of the work, the contractor was engaged in tearing down the old open approach walls and excavating at the east end of his contract. As no sheathing had been driven at this end, he excavated only a width of about 20 ft. along the center line of the tunnel, for a depth of about 10 ft. below the old track grade. The material encountered here, and in fact on the whole work, was a soft blue clay, excavated almost entirely by means of "clay knives." With three men on a knife and one mucker, the excavation was carried on very rapidly.

As soon as the pile driver had finished on the west half of the work, the excavation was started at that end, and followed by the bracing. Work was prosecuted day and night.

The work of the C. & N. W. Ry. Co. compelled them to use a short plank sheathing on either side of the tunnel, and although this was only 3 in. thick and 12 ft. long, the contractor attempted to take advantage of it in his work, but before half of the job was finished the general opinion was that a better plan would have been to disregard this planking and bracing entirely.

Briefly, the bracing consisted of 12 in. by 12 in. waling pieces butting against the steel sheeting. Timber cross struts, 28 ft. long, spaced about 13 ft. centers, east and west, and 6 ft. vertically. They were wedged to the C. & N. W. Ry. columns, while short struts extended from the columns to the waling pieces. These short struts were made up of 12 in. by 12 in. timbers and were held in position with steel screw jacks. The cross timbers, extending from column to column, besides being wedged, were fastened to the horizontal steel struts of the C. & N. W. Ry. structure by means of vertical 1-in. rods placed at each end and stiffened with two vertical and longitudinal timbers on each side of the center line of the tunnel, and so spaced that they could be used as framework for the forms of the bench wall. The cross struts that were located midway between columns were taken care of practically in the same way as outlined above, except that they were not directly dependent on the C. & N. W. Ry. structure, but extended clear across the cut from wale to wale. There were an average of 5 sets of timbers for the entire depth of the excavation, each tier being 6 ft. apart. The timbering was substantial, but the screw jacks had a tendency to work loose and consequently required daily maintenance. They had an advantage, however, in that they could be easily removed. It was the practice to take out as many of these short braces as was practical while the walls were being concreted, thus puncturing the sides and waterproofing as little as possible.

A concrete mixer of ½ cu. yd. capacity was placed at the east end of Section 1 on the center line of tunnel, about 4 ft. below street level, so the materials could be wheeled from storage piles without the use of an inclined runway. The concrete was carried to its destination by means of the overhead cable system, and was dumped from the cableway to a platform in the center of tunnel, then shoveled into place or into a chute leading directly to the forms. The first concrete was placed in the invert October 28th.

The placing of the reinforcing metal caused more or less confusion at the start, on account of the class of work being unfamiliar to the contractor's men, as well as to the inspectors, but this gradually wore off as the work advanced. As soon as excavation was completed to the required grade for a distance of 30 ft. or so, the concrete invert was placed, and shortly afterwards the walls brought to the required height. In the double-bore arch section the side walls were brought up to the springing line, and the center wall was built at the same time as the arch.

On November 20th the first arch from 0+70 to 0+81 (west end of work) was concreted. Steel forms consisting of 6-in. channel irons, bent to the required radius, and steel lagging 3 ft. long were used. The lagging was hardly a success, for it was not easily held in position, neither was it tight, and the result was that large lips formed on the finished surface.

The waterproofing course of asphalt and brick was built up after the walls were completed. The space between the waterproofing and the steel sheeting was filled with sand, as it was thought by the contractor that by this means he would be enabled to easily recover his steel sheeting, but after rigging up an expensive sheeting puller which spanned the full width of the tunnel, he found that it was cheaper to leave the sheeting in place. This sheeting puller consisted of two 20-in. I-beams, spaced 30 in. centers, each 62 ft. long, which spanned the open cut. These I-beams were trussed both vertically and latterly with two rods, each 2 in. in diameter. They were mounted on built-up steel towers located on each side of cut. Each tower was 7 ft. high and had a base about 4 ft. by 7 ft. These were mounted on car trucks, which in turn ran on a 4 ft. 8½ in. gauge track, built parallel to the cut. The hand hydraulic jacks were set on the I-beams directly over the sheeting, one on each side. They were operated with the use of Jackohol Oil and had a capacity each of 100 tons. The jacks were fastened to the piles by means of a heavy chain. The total weight of the puller was 6½ tons. To operate the puller the piles were first started with the jack, then after they had been raised about 2 ft., a block and tackle was fastened to the pile, with one end of the rope run to a hoisting engine, which finished the job. The sheeting puller was hardly a success for speed or strength, and the heavy strain on the I-beams caused them to buckle badly, and consequently it became necessary to stiffen them with 12 in. by 12 in. wood fillers placed between the two I-beams. An average of 3 or 4 piles in 8 hours was a fair day's work.

During the last half of the month of December the weather was such that but little work could be done, so the contractor's force was reduced to one shift and the work practically closed down for the winter. The work under contract was about half completed.

On resuming work in 1910, there were about 50 lineal feet constructed partially by tunneling and partially by open cut. All the rest of this section was done by the open-cut method.

Section 2:

In preparing plans and specifications P-5 for the reconstruction of Section 2, which includes the river section of the tunnel, there was some difference of opinion in regard to the question of whether it would be better to utilize the steel girder and concrete roof which had been built in the river section of the tunnel in 1906 and 1907, or reconstruct the tunnel from end to end. After considerable study, the Board of Supervising Engineers decided to ask for bids under three propositions:

1. For entirely reconstructing the tunnel. See Figs. 17 and 18.
2. For underpinning the roof in the river section and rebuilding the remainder of the tunnel. All according to plans prepared by the Board. See Figs. 19 and 20.
3. For rebuilding the tunnel under a proposition by the contractor.

"If the contractor desires to submit more than one method for doing the work, he shall make a separate proposal for each method (which proposal, in each case, shall embrace the whole work within the limits shown on the drawings), but the sum deposited with his proposal will cover one or more proposals submitted by the same bidder. The Chicago Railways Company reserve the right to accept any of the different methods submitted as a whole."—(Specifications, P. 5, par. 86.)

Under proposition No. 1, the river section was to be a double-bore reinforced-concrete tunnel which extended each way until it became necessary to span both tracks with a single-bore arch in order to provide head room for the cars on a temporary grade leading to the street surface. The invert and side walls, however, were carried along on a lesser grade, which was to be the permanent grade of the tunnel, until a point was reached where, at the east end of the work, the temporary grade was sufficiently high to allow the construction of a double-bore arch beneath the temporary track. This latter portion of the double-bore arch was to form the connection to a future subway.

Under proposition No. 2 the tunnel in the land sections was to be similar to that proposed for proposition No. 1, but, for the river section, a method of underpinning the steel girder roof by means of a tunneling process was outlined. We had proposed to first build a cofferdam in the river which, when unwatered, would have reduced the pressure on foundations of the existing roof; then drive a pilot drift sufficiently large to work in, along the center line of the tunnel at the same elevation of the invert. From this drift, side drifts 5 ft. wide and about half the height of the wall were to be carried out to the side walls. The lower part of the wall and the invert of this side drift were then to be concreted. Several of these side drifts could be worked simultaneously at about 25 ft. apart, then the upper part of each side drift excavated and the foundation of the roof underpinned. Then the 5 ft. adjoining each section could be excavated and concreted, and this process repeated until the entire river section was completed. This method is shown very clearly in Figs. 19 and 20.

The bids were opened on September 22, 1909, and while several contractors were willing to construct the tunnel under either of our propositions, only Geo. W. Jackson, Inc., submitted an alternative proposition.

After tabulating and comparing the bids, it was found that proposition No. 3 as submitted by Geo. W. Jackson, Inc., was very much lower than the proposals submitted by any other contractor. Mr. Jackson explained the difference by preparing certain plans which he accompanied by a detailed explanation. He supplemented his written description by a statement that if another contractor was awarded the work under an open cut method that the Disposal Station of the Geo. W. Jackson, Inc., company, just south of the tunnel, would be practically put out of commission during the period of tunnel construction and would entail a great loss to his company.

To Geo. W. Jackson, Inc., was awarded the contract for $590,000 under proposition No. 3, which covered all of the work called for by the plans and specifications (proposition No. 2) for reconstruction work prepared by the Board of Supervising Engineers. Any extra work done but not called for by plans or specifications was to be carried out at unit prices named in contractor's bid, under proposition No. 2, except that the contractor was to absorb any expenditures necessary in building, maintaining, and removing all cofferdams, sheeting, and bracing, and protecting buildings.

Method of Construction: The working plans as submitted by the contractors in connection with their alternative bid on reconstruction work under proposition No. 3 embody the plan outlined by the Board in proposition No. 2, previously described and illustrated in Figs. 19 and 20, with minor modifications as to the method of construction. These modifications comprised the following features:

1st. The cofferdam construction contemplated for relieving the load on the roof of the river section was omitted.

2nd. The tunneling work was to be performed by the pneumatic process.

3rd. The central drift with laterals was replaced by side drifts under the two walls.

4th. Structural steel arches used as false work were to be introduced every three feet. These were to be left in the concrete and replace the reinforcing rods at these points.

5th. In place of waterproofing, the contractor proposed to apply an equal thickness of concrete of the same mixture as used in the arch and walls, and after completion of the work, to force grout into all voids and openings behind the walls and in the tunnel structure, in order to prevent seepage of water into the tunnel.

Under the contractor's guarantee to furnish a complete tunnel as called for by the plans and specifications submitted by the Board, the working plans of the contractor were approved.

The contractor proposed to sink one working shaft near the west bank of the river and another shaft on the east side, just east of Market street. From the bottom of these shafts he intended to drift east and west about 25 ft. from the bottom of the shaft, where air locks would be constructed. These air locks were to be about 18 ft. long and 6½ ft. wide, with branch tunnels about 6 ft. wide and 7 ft. high, extending a short distance beyond the air locks, then branch off at an agle of about 40° until they intersected the north and south walls of the tunnel.

Referring to Fig. 21, three typical sections of the tunnel are shown with the method of drifting under the two side wall foundations.

1st. The River Section.
2nd. The Single-bore Section.
3rd. The Double-bore Section.

These drifts were lagged with 3 by 8 timber lagging on 5 in., 6½ lb. channel centers for their entire length, and then concreted. At a point about 5 ft. above the bottom of the drift, horizontal reinforcing struts of 4 in. I-beams were used and left in place when the drift was concreted. Upper drifts 2-2a were advanced in a similar manner to lower drifts 1-1a, strengthened by I-beam columns designed to carry the weight of the superimposed foundations of the existing steel girder and concrete roof. These I-beams were left in place when the drifts were concreted. All outside lagging was also left in place. The earth core, upon the completion of the side walls, was excavated and the invert placed, skew-backs for which had already been provided in the lower drifts.

For the other types of tunnel construction, Fig. 21, AA and CC, the drifts 1-1a, 2-2a, 3-3a and 4-4a were pushed forward in a manner similar to that outlined for drift 1-1a for the River Section. The arch roof of the single bore arch section, CC, DD and EE was to be placed by cutting through the side walls of the old tunnel in 3 ft. lengths to permit connecting the latticed arch trusses with the channel lagging centers left projecting above drifts 4-4a. As the approach walls of the open cut extended down to the top of the double-bore arch, it was necessary to drive steel sheeting to support the earth pressure of the adjacent property during the progress of excavating the core material between the sheeting. Consequently, on all double-bore tunnel work, the latticed arch trusses were placed from the open cut and not as indicated above.

This method of drifting by successive levels necessitated the introduction of the vertical reinforcing rods in short lengths, cut according to the height of the drift. In order to secure practically continuous reinforcement in the finished structure, throughout the entire height of the wall, a key was left in the upper corners of each section concreted, when the reinforcing rods were overlapped as much as possible and held together by "U" clamps. This type of overlapping joints was the subject of special tests, and a minimum overlap of 8 in. with a single pair of clamps was decided upon for use in all work on this tunnel. These tests are reported more in detail later.

Contract Section 2—Construction Work: On October 13, 1909, the contractor began to clear the tunnel site west of the river and on the 19th of the same month he started to sink the west working shaft. This was a circular shaft 7 ft. inside diameter, lined with concrete approximately 10 in. thick, extending from the street surface to a few feet below the proposed invert of the new tunnel. From the bottom of the shaft the short east and west drifts, the air locks, and the branch drifts were constructed, as outlined above. These drifts were mined out for a distance of 3 ft. and lined with 10 in. of concrete before mining was resumed.

The concrete lining was continuous inside of the lock, except just inside the first or outer door, where a 12 in. strip of clay was left exposed. This space, commonly termed the "dope-ring," extended completely around the tunnel and prevented the compressed air from flowing around back of the lining and leaking outside of the tunnel. Every week or so this dope-ring was washed with a neat cement grout. A similar ring was placed just outside of the second or inner door of the lock, so that any leakage of air back of the lining would either be intercepted at this point or at the ring inside of the lock.

Power Plants: The power plant of Shaft No. 1 on the west side of the river occupied about 1,700 sq. ft. and is equipped with boilers, feed water heaters, pumps, air compressors, and hoisting engine, all steam operated. While the plant at Shaft No. 2, just east of Market street, covered about the same space as the plant at Shaft No. 1, it had a complete and independent equipment all operated by electric power, with the exception of a steam hoisting-engine. A trestle was built from the head house to a dumping platform at the east dock of the river so as to dispose of the debris by means of scows which towed it out and dumped it into the lake.

The tunnel structure was completed in January, 1911. The pump house and drainage system was completed early in the spring of 1911.

LA SALLE STREET TUNNEL.

The La Salle Street Tunnel, extending along the center line of La Salle street from about Randolph street on the south to Michigan street on the north, was built in 1869-1871 by Moss, Chambers & McBean. The construction in general was similar to the Washington Street Tunnel, the only differences being that the steepest grade was 1:20 instead of 1:16, the foot passage was made higher, and the outer course of brick in the arches was laid in asphalt instead of being simply covered with a layer.

The total length was 1,887 ft., of which 1,170 ft. was brick arch, about 180 ft. of iron girders with brick jack arches between them, and the remainder about equally divided between the north and south approach. The total cost was $566,000.

The tunnel was turned over to the Union Traction Company in 1889 and converted into use for the north side cable system, but no changes were made in the tunnel structure.

Proposed Alterations in 1906:

Under the same ordinance which provided for the lowering of the Washington and Van Buren street tunnels, the river section of the La Salle Street Tunnel was also to be lowered, Fig. 22. The designs contemplated a new roof in the river section that would give a roadway 26 ft. clear and a smaller tunnel on the east 7 ft. 6 in. square, this latter to accommodate water pipes, electric wires, cables, etc. The roof was to be of steel girders, 4 ft centers, with concrete jack-arches between them. The west end of the girders were to rest on chases cut in the old west wall, and a new east foundation was to be built in the foot passage. The girders were built in two sections spliced at the center so they could be erected without seriously disturbing the bench walls which they pierced and which were to be afterwards cut away. A waterproof course of brick laid in asphalt was to cover the whole new work and over this was to be a protective course of concrete. The finished roof was to be at —26 ft. 5 in. C. C. D. for 190 ft. in the center of the river and rising to —23.0 at the dock lines. The river at La Salle being 287 ft. wide and the new roof extending under watertight bulkheads 14½ ft. inside of the dock lines made a total length of new work of 316 ft.

Under an agreement made with the city, the Commissioner of Public Works was to take care of the 36-in. water main in the foot passage during the progress of the work and then lower the main to the new floor when the latter was finished. After the Telephone Company had removed their cables, the City supported the water main in wire rope slings about 8 ft. apart attached to long turnbuckles which were suspended from two 8 in. by 12 in. timbers, the ends of which rested in niches cut in the brick walls at the springing line. Above these timbers and with the apex at the crown of the arch, the Union Traction Company had erected "A" frames, along the sides of which they had placed their cables. The brick saddles were cut out from under the water main and a small amount of cutting was done on the invert. This was all that had been done up to November 24, 1906.

Sometime during the night of the 24th, a leak was sprung in the east wall at one of the timber supports put in by the City about 30 ft. south of the south dock line. This leak did not flow more than 100 gallons per minute, but later developments showed that the water had made its way down along the side walls and found some channel under the old invert. During the night of November 29th, the water broke through the invert about 30 ft. south of the dock line and soon flooded the tunnel. About 1,500 cu. yds. of clay was dumped along the south dock line and the dredge worked about two days adding river clay to that dumped by the scows. This seemed to block the leak and on December 2nd, three pumps, a Norris 8-in., Deane 7-in. and a Nye No. 5, started to work. On December 4th a No. 4 Ferguson replaced the No. 5 Nye. On December 8th a 10-in. Morris was installed in the north side of the tunnel, and the discharge pipe led out through the north air shaft and into the river. The pumping then amounted to about 150,000 gallons per hour, while the leakage was about 50,000 gallons. Mr. John Z. Murphy then took immediate charge of the work and at 8:00 P. M. all the pumps were started and the leak was practically uncovered at 11:30 P. M. The men were then put to work to stop the leak. Upright planks were firmly secured north of the leak, bags of cement and sand were forced down into the hole, and 8 in. by 8 in. timbers 8 ft. long placed on top. These were jacked hard down and the spaces between caulked with oakum. The dam, or rather bulkhead, was extended about 8 ft. on each side of the leak and 4 ft. high. It completely filled the space between the east wall and water main. The work was finished at 5:20 A. M. December 8th and, at that time, practically no water was leaking into the tunnel, but the pumping continued until about noon, when the water suddenly began to gain on the pumps and by 4:30 P. M. it had risen nearly 7 ft. The 10 in. Morris pump was disconnected and as quickly as possible taken out of the tunnel. The water was then rising about 10 in. an hour and all pumping was discontinued. The tunnel was completely filled to the river level at 11:30 A. M. the next morning.

At a conference between Chief Engineer Samuel G. Artingstall and the City Engineer, they decided to abandon the tunnel and recommended removing the river section so as to conform to the requirements of the United States Government.

The plan of removal consisted in first dredging a deep trench along the outside of the walls, then drilling the walls and roof, blasting as much of these as possible, and letting the debris fall into the tunnel or a trench alongside; then dredging any obstruction left from the blasting.

On March 4th, 1907, we started dredging the trench along the west wall and drilling near the north dock. The first shot was fired at 1:15 P. M.; 17 holes were drilled the first day and about 50 lb. of 70% Forcite exploded. A diver explored the site after each shot and any large pieces of debris were reshot. The drill boat continued to work along the tunnel at a rate of about 20 ft. per day until near the south dock. Here the ashes, which had been dumped by the fire boat, continually blocked the drill holes so only about 8 ft. a day could be accomplished. After the walls had been blasted, the dredge worked across the tunnel, dredging everything to 28 ft. 540 holes were drilled and 1,290 lb. of 75% dynamite used in blasting the roof and walls.

The drill boat was discharged on March 21, 1907, and the remainder of the work dredged. All work was finished on April 9, 1907.

PROPOSED RECONSTRUCTION.

For the proposed reconstruction of this tunnel there was submitted for consideration the following:

1. A single-bore brick tunnel of 26 ft. span.
2. A single-bore reinforced concrete tunnel of 26 ft. span.
3. A twin-bore brick tunnel. Each bore 14 ft. span.
4. A twin-bore reinforced concrete tunnel. Each bore 14 ft. span.
5. A combined twin and triple bore reinforced concrete tunnel.
6. And a triple bore steel shell for use in the river section in combination with a triple-bore land tunnel.

After a consideration of which, the Board selected the design for a twin-bore reinforced-concrete tunnel, which also was the one of least estimated cost.

The general design for the reconstruction of this tunnel provides for a permanent double-bore tunnel extending from Randolph Street on the south to Michigan Street on the north, a distance of 2,000 feet. Each bore will accommodate a single track with ample room along the outside walls for cables and conduits. The design is such that connection can be made at either end with a subway without seriously interfering with traffic through the tunnel; and entrances are also provided at either end for the temporary use of the tunnel pending the settlement of the Subway Question. As will be noted by referring to the general plan and profile, as shown on Fig. 23, the permanent track of the tunnel is maintained at a 3% grade from the river section toward either end, while the temporary track is carried as a descending 9% grade from the present street level to an intersection with the permanent or 3% grade in the tunnel. Where the temporary track is sufficiently high it is carried above the permanent tunnel.

Before taking up the design in detail, it may be well to state the several requirements which had to be observed and for which provision had to be made.

1st. The tunnel can be ultimately the connection between the territory north of the river and a subway in the business district.

2nd. Provision had to be made for an extension of the subway north of Michigan Street.

3rd. The tunnel is to be used temporarily by cars coming to the surface at either end.

4th. The street over and along the tunnel must be maintained for vehicular traffic after the present work is finished.

5th. The design must be such that there be a minimum interference with car traffic during the change from surface to subway operation.

6th. The probability of a bascule bridge being built across the river at this street, the foundations to be carried over the tunnel to caissons sunk alongside the tunnel walls, and provision to be made for a gravity dam in case the bridge foundations are built subsequent to the tunnel.

The first two conditions were easily disposed of, but the temporary approach, the maintenance of adequate roadways along the temporary approach, and the construction of the former so as to be easily removed, introduced several interesting and complex problems into the design, as will be seen later.

On account of the ultimate use of the tunnel, as above stated, the side walls are continued in a straight line from end to end, and all permanent construction is utilized as far as practicable in the temporary work. The twin bore is maintained as far as possible and still provide sufficient head room for cars while passing from the 3% grade to the 9% grade. The two tracks are then spanned by a single arch, the abutments of which are the permanent tunnel walls. As there is a difference of 4 ft. 3½ in. between track centers in the tunnel and on the street, the tracks are drawn together in the single-bore tunnel. The arch of the latter follows a line parallel to the 9% grade until the fill over the crown is insufficient to resist the rising of the same. And in order to give as much of unobstructed street surface as possible, the arch construction is carried still farther, but struts are introduced in the arch which, if there is any tendency to rise, will act as a slab while the walls will then act as a beam and the struts act as columns; should any excessive load, however, be placed upon the street above this point the structure will then act as an arch without affecting its stability.

As the height of the side wall rapidly increases to a maximum of about 40 ft., temporary concrete struts from wall to wall are introduced under the temporary track, and also near the top of the wall, to resist the horizontal earth-thrust. The free span is thus reduced to a maximum of 28 ft. and the wall acts as a continuous beam. As will be noted, the streets are also carried alongside of the open approach and the wall overhangs the tunnel to provide the required width of roadway. The use of struts in this work effects an enormous saving in excavation by eliminating the heel, which would be necessary in a cantilever wall of this height. The walls of the open approach above the completed subway tunnel, at either end, are pure and simple reinforced concrete walls. The design of the walls is somewhat out of the ordinary, but it was made with the idea of utilizing the tunnel centers as forms for the "overhang."

As mentioned above, the permanent work will be built wherever practicable and, consequently, in the single-arch tunnel the intermediate, or bench wall, of the twin-bore tunnel is to be built to a height limited only by the clearance required for the temporary track. The vertical reinforcement in the bench wall will be bent horizontal upon itself, while that in the side walls will be embedded near the surface so as to be easily accessible for use when the necessity arises. Provision has also been made for building the double arch without interfering with subway operation. See Fig. 24.

The twin-bore tunnel will be built in the river section and for a distance of 350 ft. on the south and about 200 ft. on the north, making an approximate length of 860 ft. of permanent tunnel; the remainder of the 2,000 ft. being divided between the temporary tunnel and open approaches.

In preparing the plans and specifications for the tunnel work, I tried to refrain from making any portion of the work of such a design that it would preclude open competition among the prospective bidders, and everything was made as nearly uniform as possible. For instance, we had a design for a steel plate construction for the river section, which could be built in a dry dock, or on shore, then towed to place and sunk. We also developed a method of constructing the tunnel by tunneling (this method, by the way, was submitted to the contractors for bids for the Washington Street Tunnel). But as both of these designs might have prevented some contractor from bidding, the tunnel was designed for open cut work. The specifications provided that the contractor should design his own cofferdam and system of bracing.

On account of our assumption of open cut work, the tunnel at an early stage must necessarily sustain a heavy loose "backfill" and the design was made on the basis of supporting the entire weight without counting on the arching effect within the material itself. Only the effective section was used in making the calculations, no allowance being made for any assistance from the waterproofing course of brick nor from the concrete covering same. The sections of the tunnel, which are shown on Figs. 24 and 25, explain themselves.

The drainage system provided for an 8-in. drain laid along the invert of both tunnels, and emptying into a sump near the center of the river section. A 3 ft. drain then leads to a sump which connects with a pump well north of the north dock and a 5 ft. shaft connects the pump well with a pump house on the street surface. The pump will be located in the shaft below the tunnel invert, but an opening from the shaft to the tunnel will allow pump repairs to be brought down by cars and unloaded directly into the pump chamber. This opening is sufficiently large to permit the passage of a fully rigged No. 6 Emerson sinking pump, and the chamber is large enough to install a pump of equal size and leave plenty of room to get around it. The apparently large conduit from the sump to the pump well was to enable cleaning and also to provide storage capacity which will obviate the necessity of keeping a pump-man continually on duty.

As will be noted on the general plan and profile, the North Water Street section of the Illinois Tunnel is at such an elevation that our invert will cut through their tunnel at about the mid-point. This will necessitate a change in the location of their tunnel.

The designs for the main tunnel made no provision for water mains, city cables, etc., which occupied space in the foot passage of the old tunnel, but a separate tunnel was designed which would provide ample space and be so located as not to interfere with the caissons of a bridge over the river at this street. This tunnel (Fig. 26) is a horse-shoe shape with a clear height of 11 ft. and a minor diameter of 10 ft. A brick shaft with a diameter of 10 ft. inside and about 80 ft. deep, located close to the east building line of La Salle Avenue, and just north of North Water Street, connects with the tunnel and is its northern terminal. From the bottom of this shaft the tunnel bears southwest at an angle 45° to a point underlying the center line of the east bore of the Street Railway Tunnel; an angle is then made to the south and the two tunnels are parallel until the conduit tunnel bends to the east to connect with the south shaft located in South Water Street and of similar design to the north shaft above described.

This auxiliary or "Conduit and Water Pipe Tunnel," as it is termed, is larger than is required for the immediate demands, but in view of the fact that the street railway ordinances governing the reconstruction of the La Salle Street Tunnel contemplate using the latter in connection with future subways, we designed the auxiliary tunnel so as to provide accommodations for such public utilities as might be carried by a "utility gallery" of the subway, and the location is such that a second auxiliary tunnel can be built without interfering with the existing Chicago Telephone Company's tunnel which crosses the river along the west line of La Salle Street.

CONSTRUCTION.

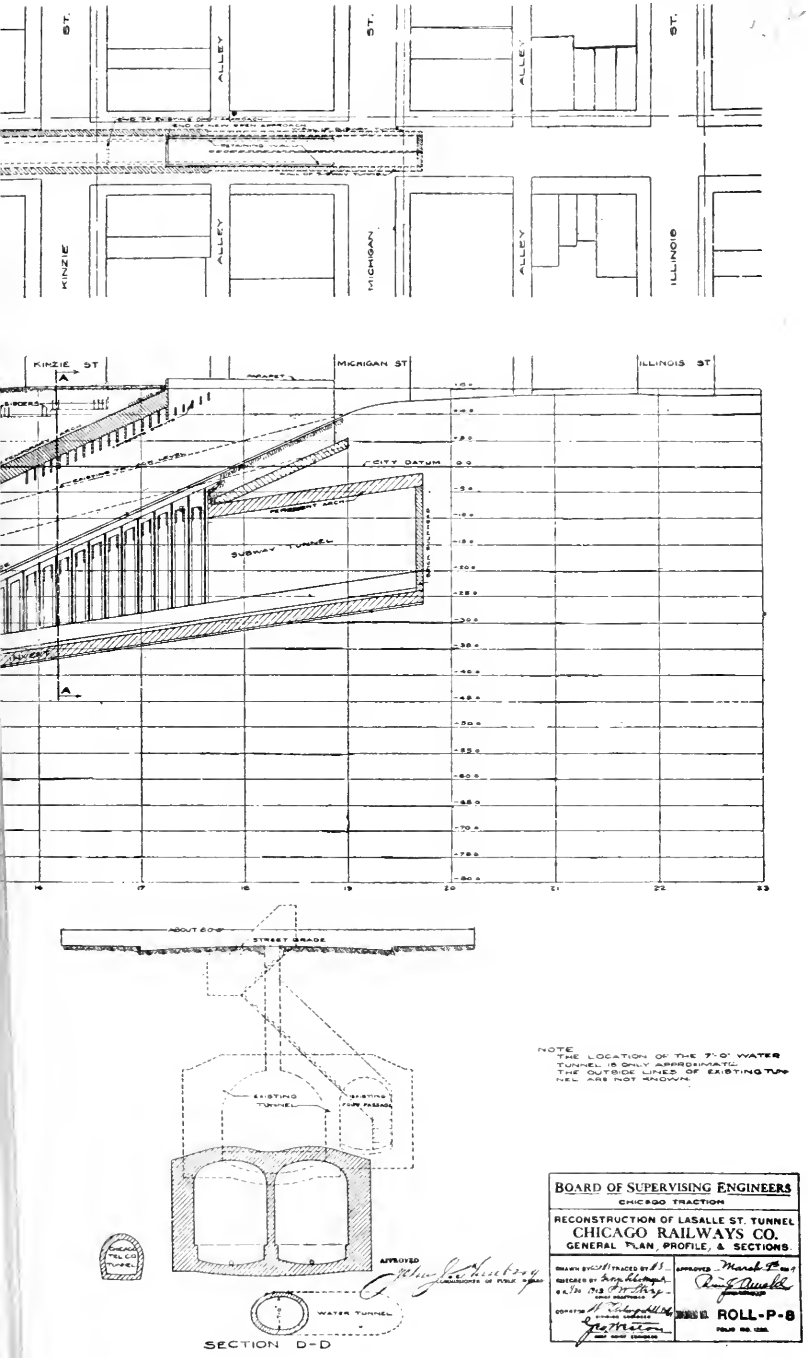
The specifications for the reconstruction of the La Salle Street Tunnel, including the Conduit and Water Pipe Tunnel, were prepared, and in response to the advertisement four bids were received:

M. H. McGovern Co.	$1,166,421.50	400 days to complete
Geo. W. Jackson, Inc.........	1,389,000.00	577 days to complete
Empire Construction Co.	1,594,605.00	700 days to complete
Great Lakes Dredge & Dock Co.	1,686,175.00	900 days to complete
Engineers' Estimate	1,178,140.00	

The contract was awarded to the M. H. McGovern Company.

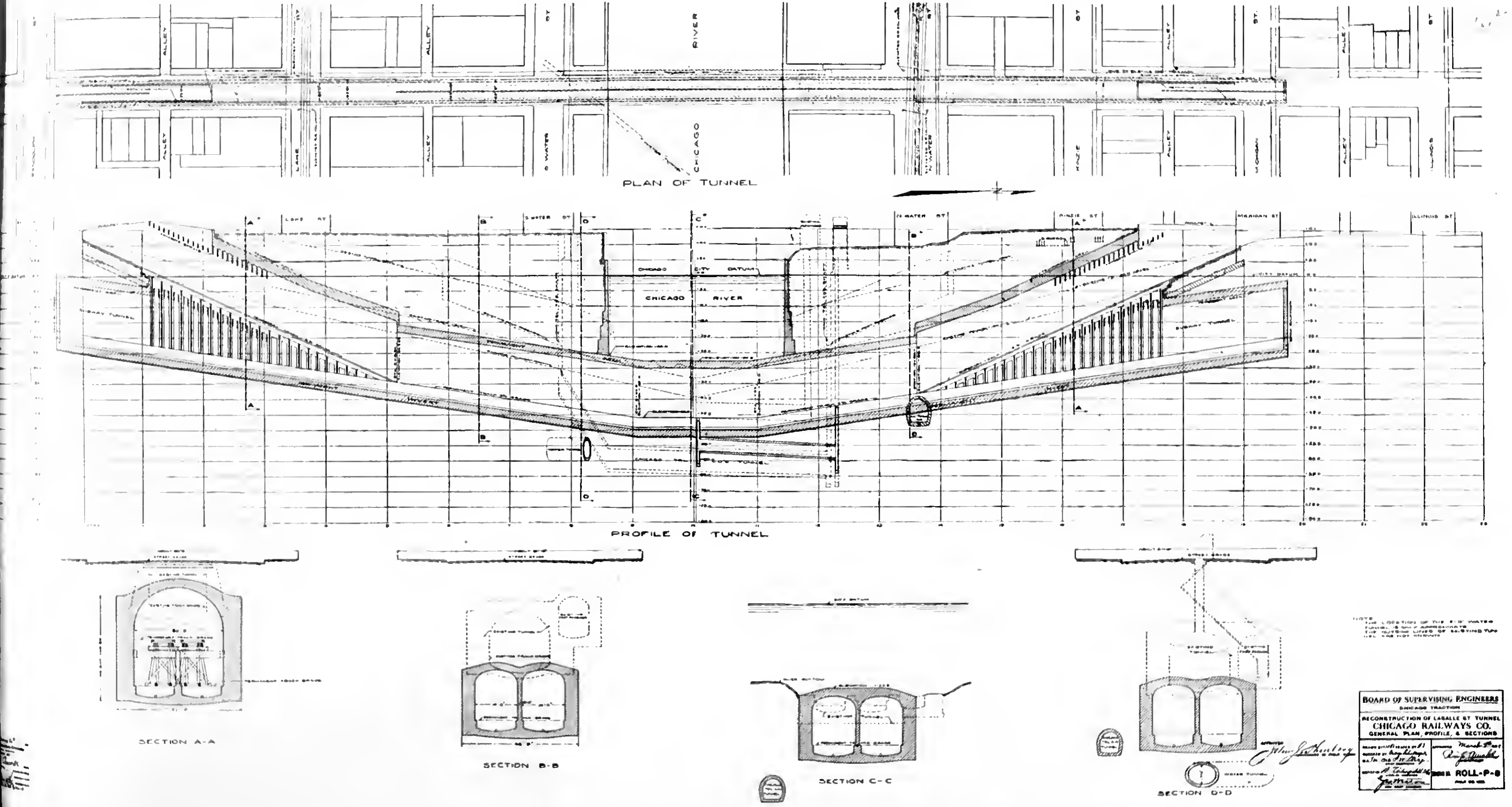
The M. H. McGovern Company accompanied their bid with the following letter:

"Chicago, August 23rd, 1909.

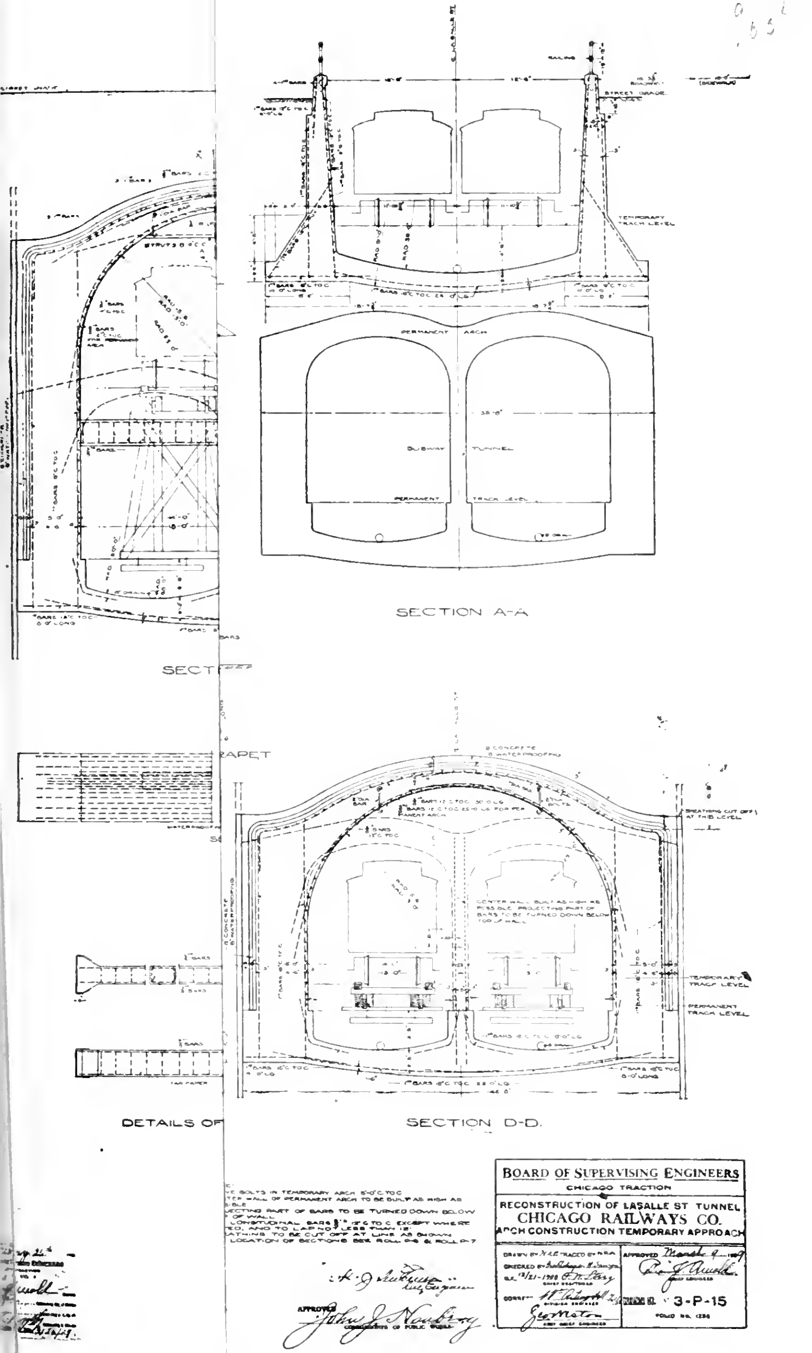


La Salle Street Tunnel. Fig. 23.

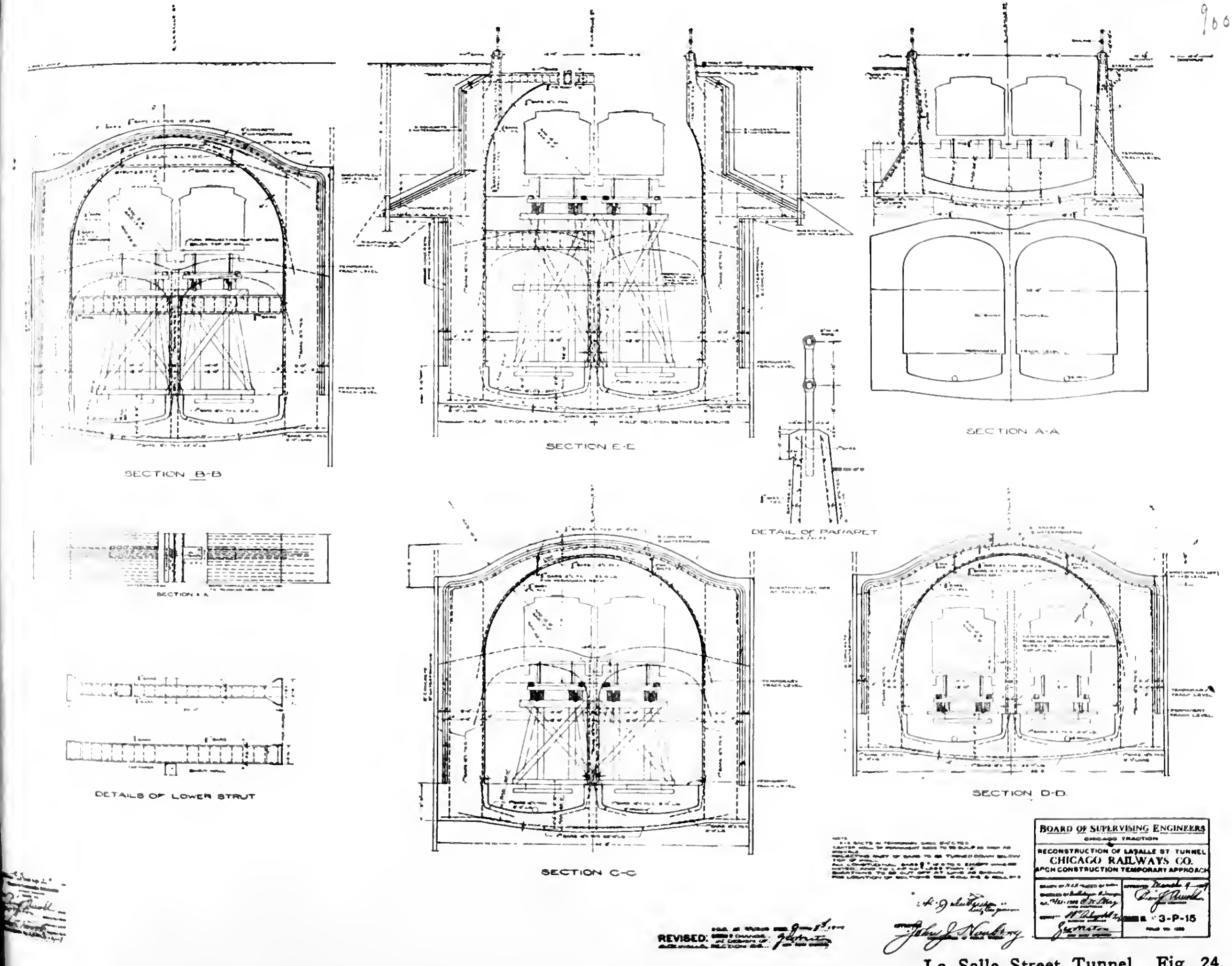
Western Society of Engineers
Vol. XVI. No. 9. Nov., 1911
Artingstall—Chicago River Tunnels.



La Salle Street Tunnel. Fig. 23.

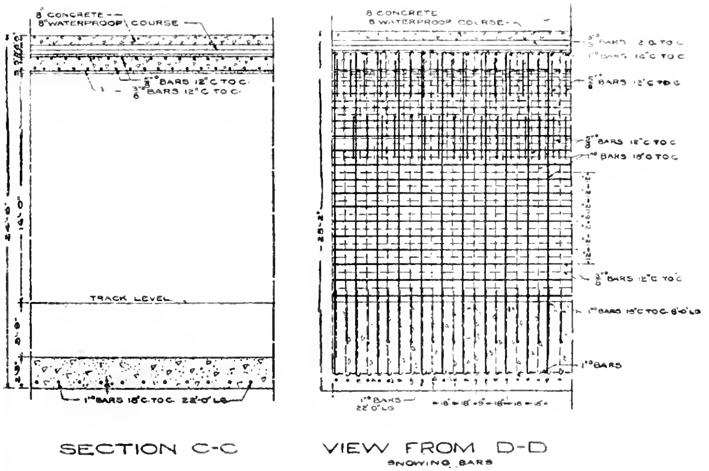


La Salle Street Tunnel. Fig. 24.



La Salle Street Tunnel. Fig. 24.

Western Society of Engineers
Vol. XVI. No. 9. Nov., 1911
Artingstall—Chicago River Tunnels.



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AN ALED STEEL WIRE FOR SPLICING TO BE No 16 B & S GAUGE
CON RETE ABOVE WATERPROOFING IN RIVER SECTION TO
BE ISHED OFF WITH 4" COURSE OF · 2 MORTAR

Engineer

APPROVED John J. Hanberg
COMMISSIONER OF PUBLIC WORKS

BOARD OF SUPERVISING ENGINEERS
CHICAGO TRACTION

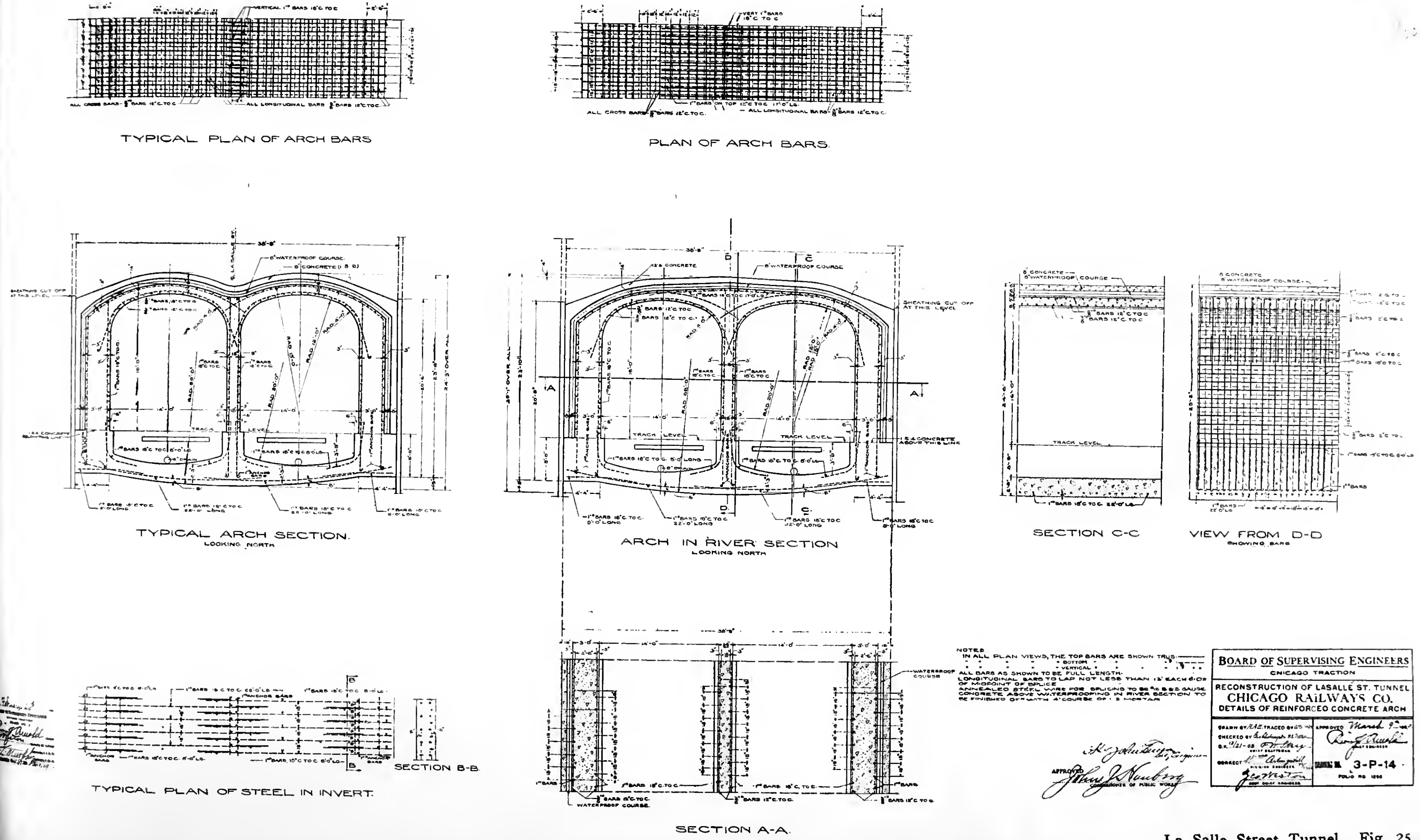
RECONSTRUCTION OF LASALLE ST. TUNNEL
CHICAGO RAILWAYS CO.
DETAILS OF REINFORCED CONCRETE ARCH

DRAWN BY H.A.E. TRACED BY G.S.
CHECKED BY
D.R. 12/21-08 F. W. Streng
CHIEF DRAFTSMAN
CORRECT W. Artingstall
DIVISION ENGINEER
Geo. Weston
ASST. CHIEF ENGINEER

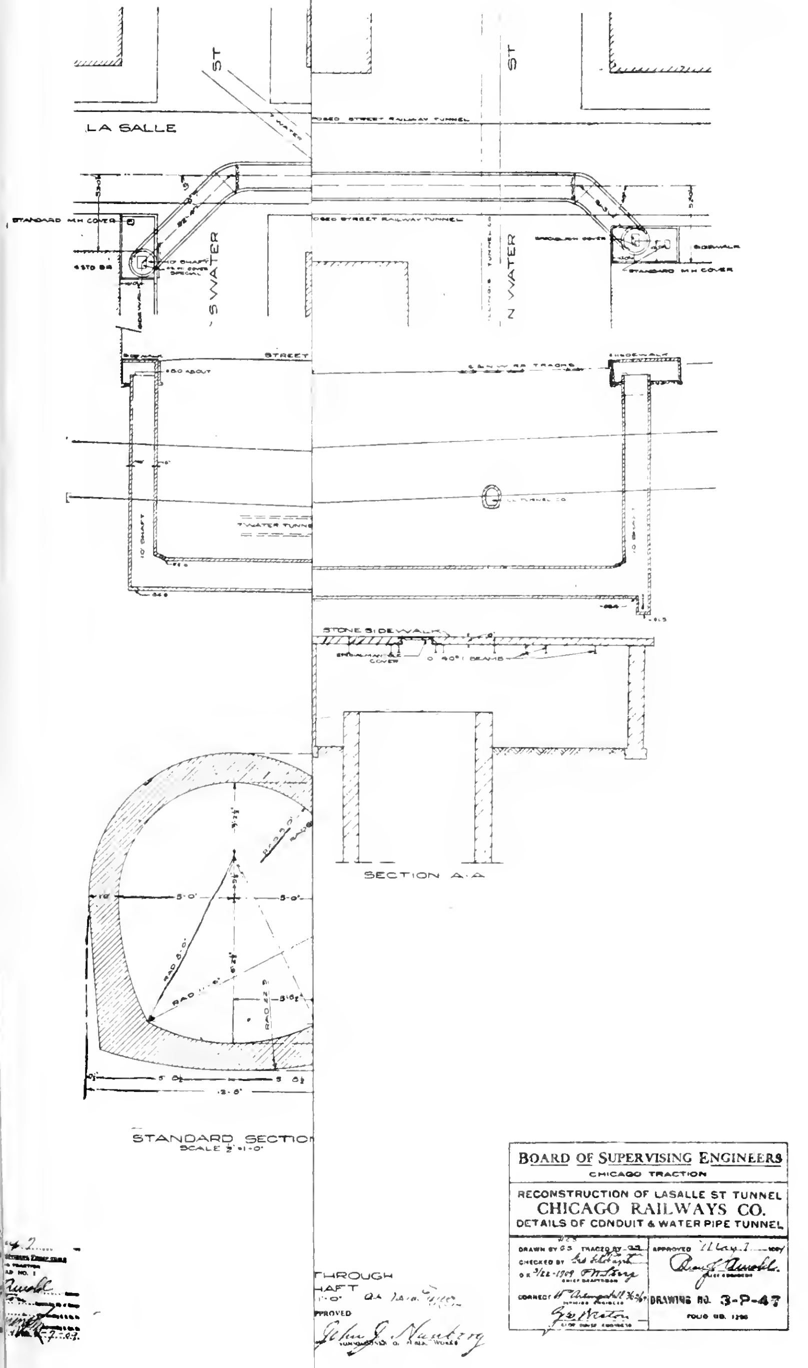
APPROVED March 9th 1907
Bion J. Arnold
CHIEF ENGINEER

DRAWING NO. 3-P-14
FOLIO NO 1265

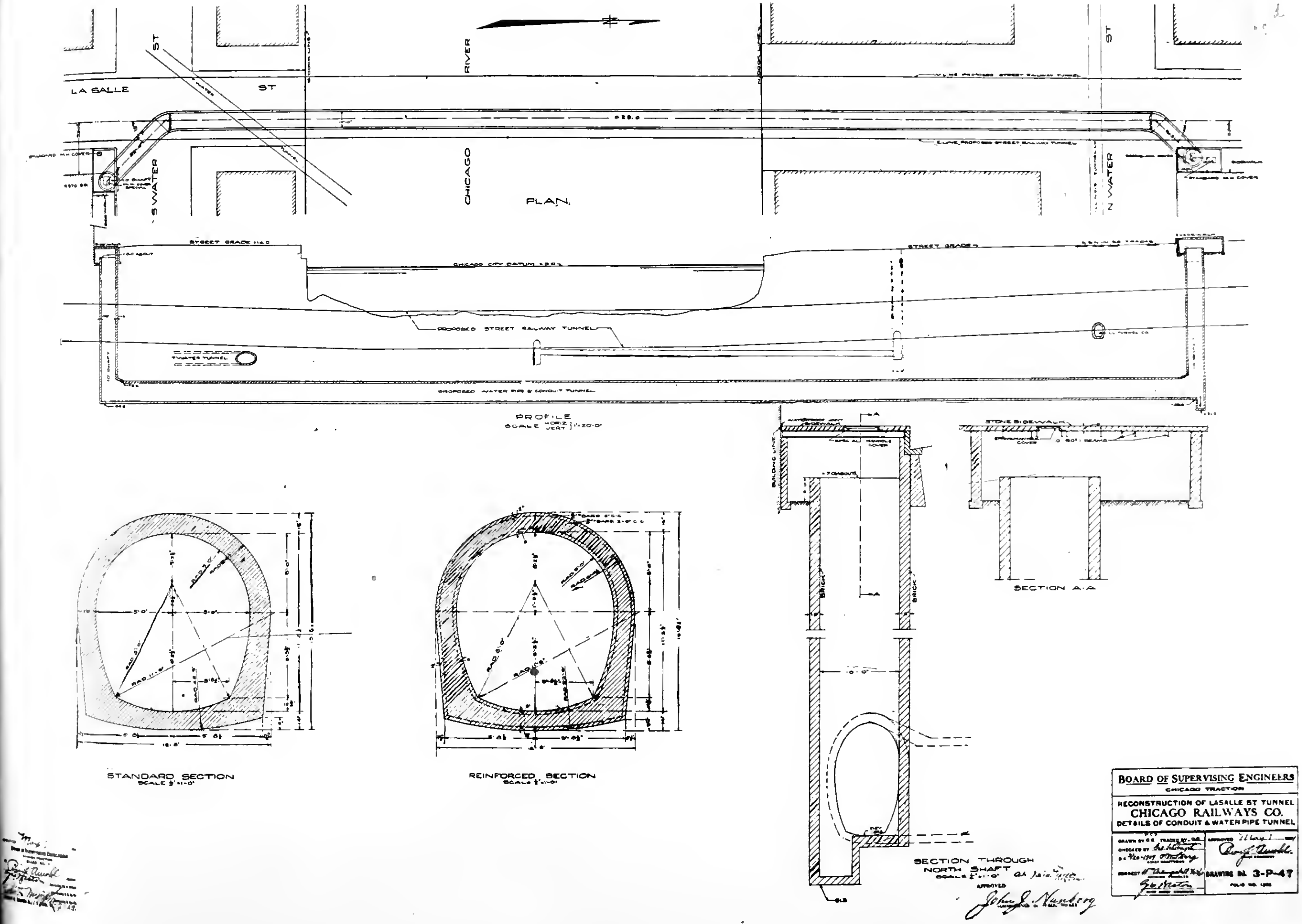
La Salle Street Tunnel. Fig. 25.


TYPICAL PLAN OF ARCH BARS
PLAN OF ARCH BARS.
TYPICAL ARCH SECTION.
LOOKING NORTH
ARCH IN RIVER SECTION
LOOKING NORTH
SECTION C-C
VIEW FROM D-D
SHOWING BARS
TYPICAL PLAN OF STEEL IN INVERT.
SECTION B-B.
SECTION A-A.
ALL CROSS BARS
ALL LONGITUDINAL BARS
SHEATHING CUT OFF AT THIS LEVEL
WATERPROOF COURSE
TRACK LEVEL
38'-8"
NOTES
IN ALL PLAN VIEWS, THE TOP BARS ARE SHOWN THUS
" " " " " BOTTOM " " "
" " " " " VERTICAL " " "
ALL BARS AS SHOWN TO BE FULL LENGTH.
LONGITUDINAL BARS TO LAP NOT LESS THAN 12' EACH SIDE OF MIDPOINT OF SPLICE
ANNEALED STEEL WIRE FOR SPLICING TO BE No 16 B.&S. GAUGE.
CONCRETE ABOVE WATERPROOFING IN RIVER SECTION TO BE FINISHED OFF WITH 4" COURSE OF 1:2 MORTAR
BOARD OF SUPERVISING ENGINEERS
CHICAGO TRACTION
RECONSTRUCTION OF LASALLE ST. TUNNEL
CHICAGO RAILWAYS CO.
DETAILS OF REINFORCED CONCRETE ARCH
DRAWN BY R.A.E. TRACED BY
CHECKED BY
O.K. 12/21-08
CHIEF DRAFTSMAN
CORRECT
DIVISION ENGINEER
APPROVED March 9
CHIEF ENGINEER
3-P-14
FOLIO NO.
APPROVED
COMMISSIONER OF PUBLIC WORKS

La Salle Street Tunnel. Fig. 25.

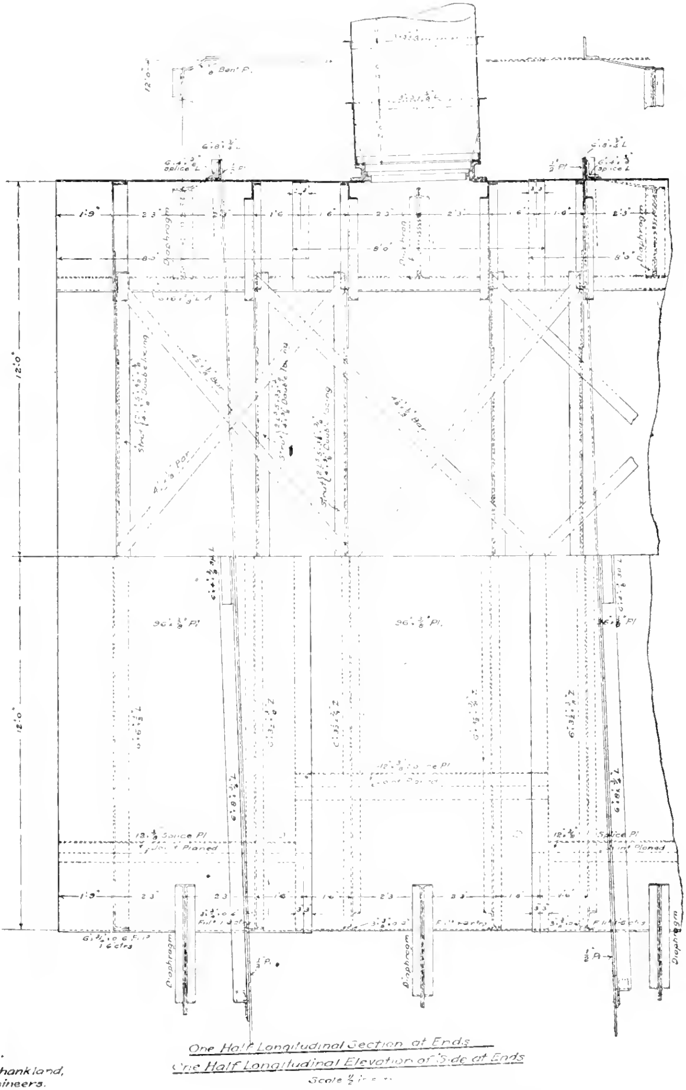


La Salle Street Tunnel. Fig. 26.



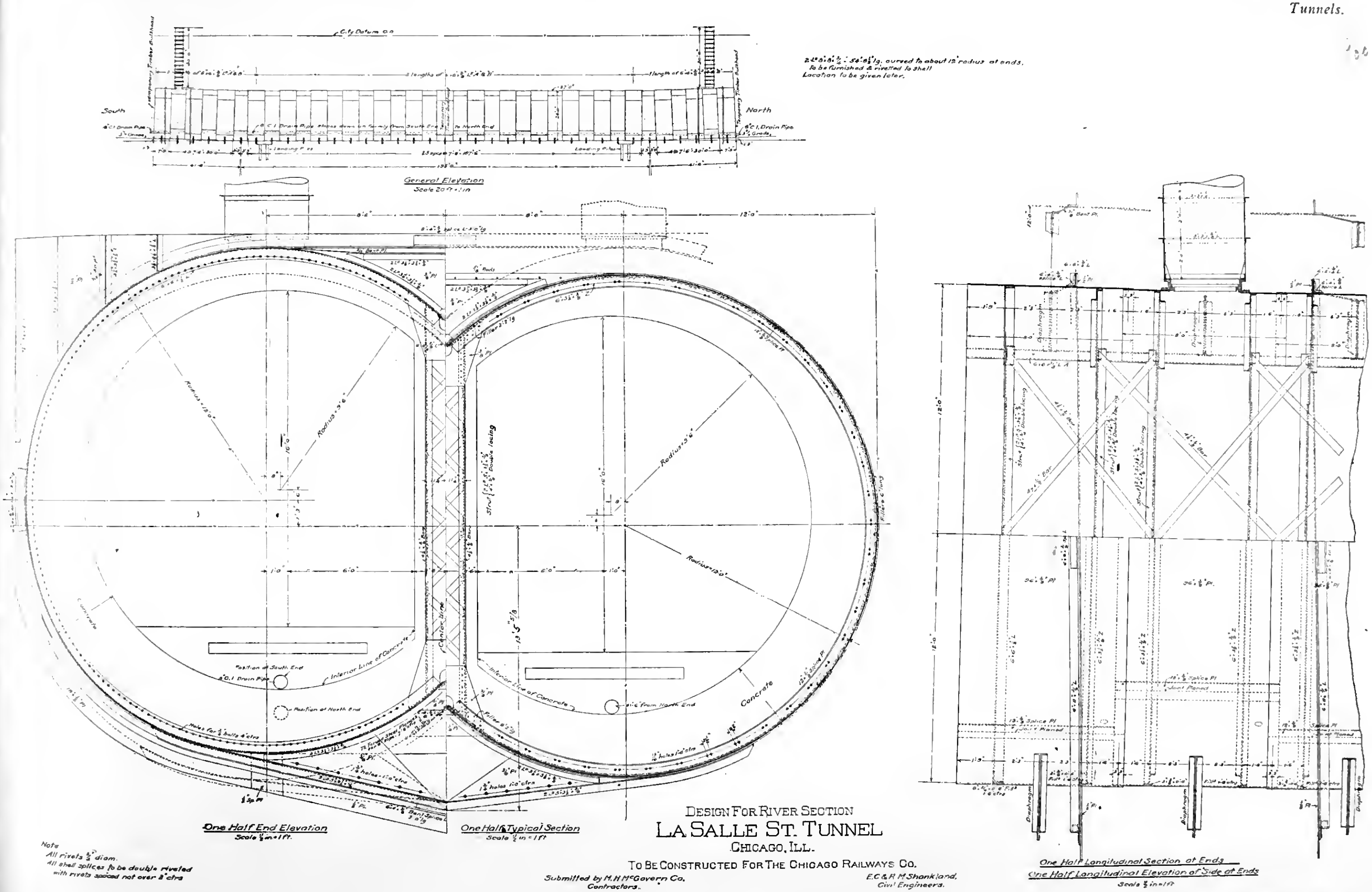
La Salle Street Tunnel. Fig. 26.

rved to about 12' radius at ends
d to shell.
er.

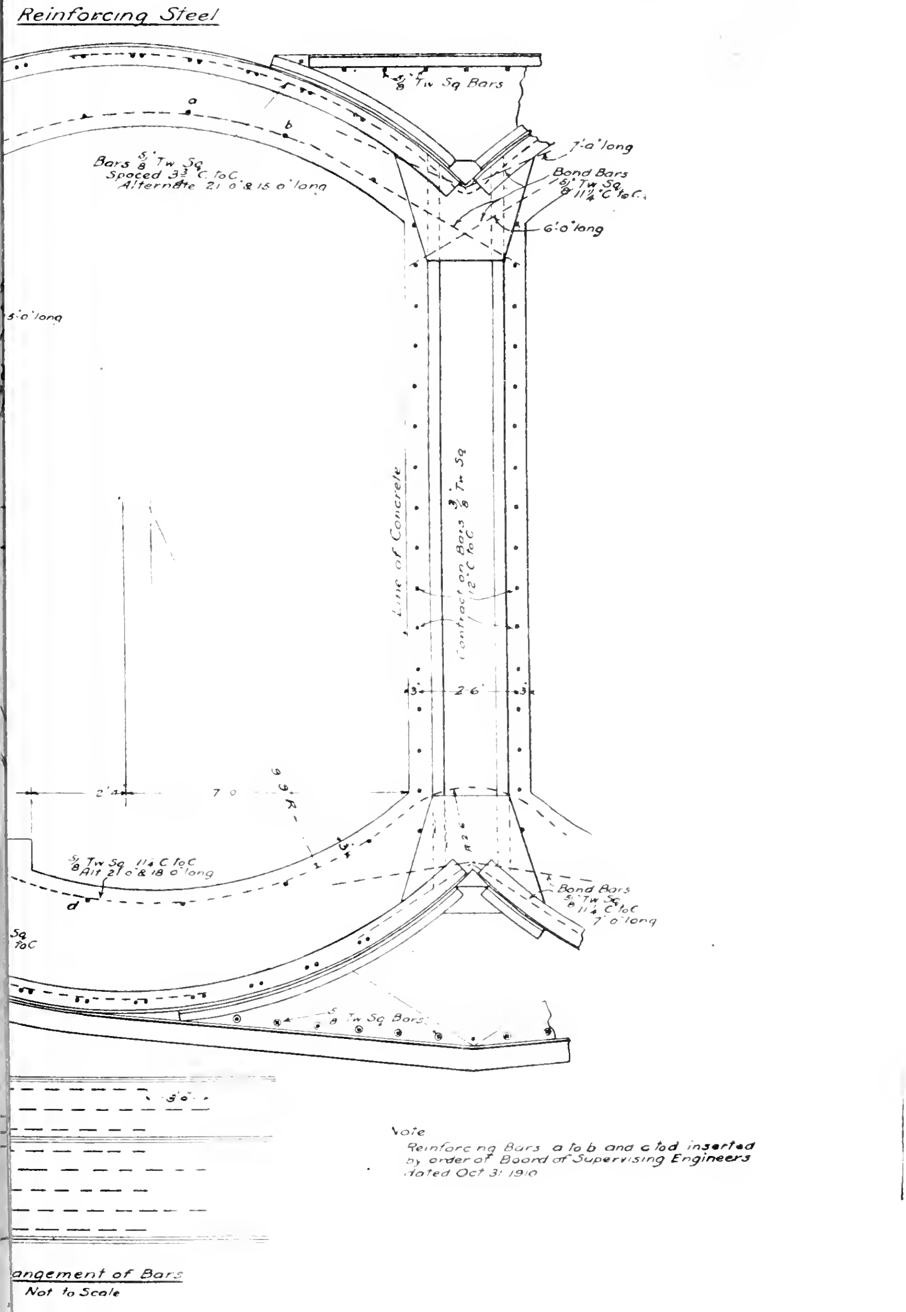


Co.
M.Shankland,
Engineers.
Applied For

La Salle Street Tunnel. Fig. 27.

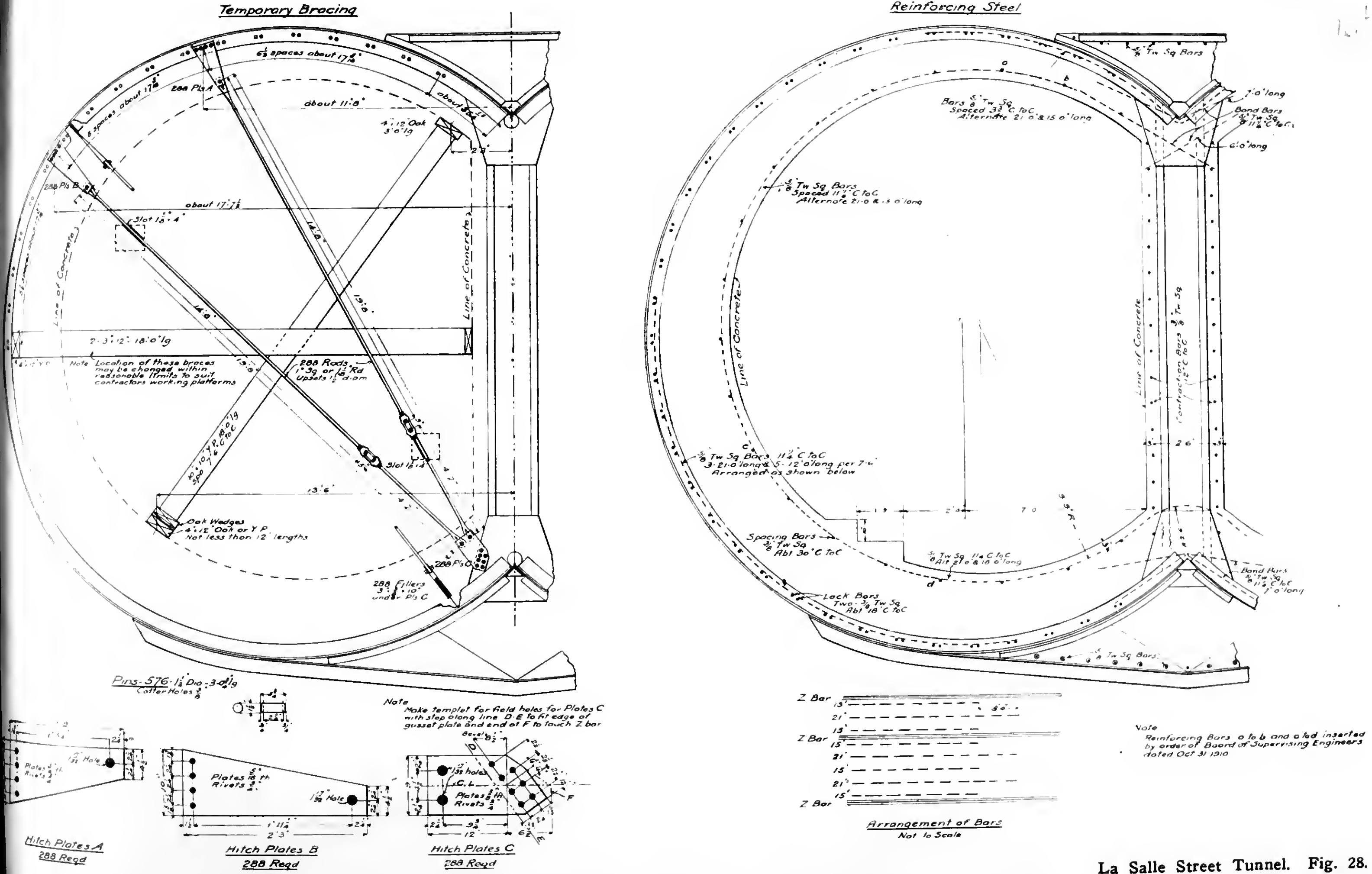


La Salle Street Tunnel. Fig. 27.


Reinforcing Steel
5/8" Tw Sq Bars
a
b
Bars 5/8" Tw Sq Spaced 3 3/4" C to C Alternate 21' 0" & 15' 0" long
7' 0" long
Bond Bars 5/8" Tw Sq 11 1/4" C to C
6' 0" long
5' 0" long
Line of Concrete
Contract on Bars 3/8" Tw Sq 12" C to C
3"
2' 6"
3"
2' 4"
7' 0"
9' 9" R
5/8" Tw Sq 11 1/4" C to C Alt 21' 0" & 18' 0" long
d
Bond Bars 5/8" Tw Sq 11 1/4" C to C 7' 0" long
Sq to C
5/8" Tw Sq Bars
3' 0"
angement of Bars
Not to Scale

Note
Reinforcing Bars a to b and c to d inserted by order of Board of Supervising Engineers dated Oct 31 1910

La Salle Street Tunnel. Fig. 28.


Temporary Bracing
6½ spaces about 17⅝"
5 spaces about 17⅝"
288 Pls A
about 11'-8"
about 8'-4"
4"×12" Oak 3'-0" lg
2'-3"
288 Pls B
about 17'-7½"
Slot 1⅛"×4"
Line of Concrete
14'-8"
19'-8"
7-3"×12"×18'-0" lg
6"×6" Y.P.
Note Location of these braces may be changed within reasonable limits to suit contractors working platforms
288 Rods 1" Sq or 1⅛" Rd Upsets 1½" diam
10"×10" Y.P. 18'-0" lg Spd 7'-6" C to C
Slot 1⅛"×4"
4'-7"
13'-6"
Oak Wedges 4"×12" Oak or Y.P. Not less than 12" lengths
288 Pls C
288 Fillers 3"×⅜"×10" under Pls C
Pins-576-1½" Dia-3-0⅝" lg Cotter Holes ⅜"
Note Make templet for field holes for Plates C with step along line D-E to fit edge of gusset plate and end at F to touch Z bar
Plates ⅜" th Rivets ¾"
17/32" Hole
Hitch Plates A 288 Reqd
Plates 5/16" th Rivets ¾"
1'-11¼"
2'-3"
Hitch Plates B 288 Reqd
Bevel 8½
D
17/32" holes
C.L.
Plates ⅜" th Rivets ¾"
9¾
12
6½
E
F
Hitch Plates C 288 Reqd
Reinforcing Steel
⅝" Tw Sq Bars
a
b
Bars ⅝" Tw Sq Spaced 3¾" C to C Alternate 21'-0" & 15'-0" long
7'-0" long
Bond Bars ¾" Tw Sq 11¼" C to C
6'-0" long
⅝" Tw Sq Bars Spaced 11¼" C to C Alternate 21-0 & 15-0 long
Line of Concrete
Contraction Bars ⅜" Tw Sq 12" C to C
2'-6"
c
⅝" Tw Sq Bars 11¼" C to C 3-21'-0" long & 5-12'-0" long per 7'-6" Arranged as shown below
1'-9"
2'-4"
7'-0"
9'-5" R
Spacing Bars ⅜" Tw Sq Abt 30" C to C
⅝" Tw Sq 11¼ C to C Alt 21'-0" & 18'-0" long
d
Lock Bars Two-⅜" Tw Sq Abt 18" C to C
Bond Bars ⅝" Tw Sq 11¼" C to C 7'-0" long
⅝" Tw Sq Bars
Z Bar
15'
21'
15'
Z Bar
15'
21'
15'
21'
15'
Z Bar
Arrangement of Bars Not to Scale
Note Reinforcing Bars a to b and c to d inserted by order of Board of Supervising Engineers dated Oct 31 1910

La Salle Street Tunnel. Fig. 28.

M. H. McGovern & Company,
No. 719 Chamber of Commerce Bldg.,
Chicago.

Dear Sirs:—

Replying to your verbal inquiry made yesterday by your Mr. Doherty concerning putting coffer dam in the Chicago River at La Salle Street in the construction of a tunnel for the Chicago Railways Company, I have to advise you that this office, acting for the United States in the interests of navigation, will not object to the construction of temporary coffer dams extending not more than sixty (60) feet into the river from the dock line and from only one side of the river at the same time. This will permit the construction in coffer dam of about 50 feet of tunnel on each side of the river. The demands of navigation will not permit putting coffer dams in the river for the remaining 180 feet of tunnel, and this portion should be built by some other method that will not obstruct the river. Before placing any obstruction in the river, it will be necessary to secure from the Chief of Engineers and the Secretary of War, by application through this office, a permit for such work. Such application should be submitted in duplicate, accompanied by several copies of plans.

Very respectfully,
Thos. H. Rees,
Major, Corps of Engineers."

The refusal of the United States Government to permit the construction of cofferdams in the river for a greater distance than 60 ft. from the dock line did not affect the contract for building this tunnel, as this contingency had been provided for in the specifications under paragraph 200:

"The contractor shall conform to all the ordinances of the City of Chicago and the regulations imposed by said City and by the United States Government in any manner affecting this work, etc."

The contractor submitted a design for a steel tube or encasement which he proposed to construct at some convenient location along the river, tow to the tunnel site and sink into place; then, by means of suitable cofferdams, connect the tube to the land sections of the tunnel. Two designs were submitted, but the one accepted by the Board was a design somewhat similar to the one developed by the Division of Tunnels in the fall of 1908.

The design (Figs. 27 and 28) consists of two steel tubes, each slightly larger than a semi-circle and symmetrical about the center line of the tunnel. The two bores are separated by a longitudinal stiffening truss consisting of steel bars and angles. This truss was enclosed in concrete at the same time the concrete lining was placed in the tubes. The steel shell is not counted on as adding to the stability of the tunnel, so concrete was reinforced to take all the stresses. The design was developed by Messrs. E. C. & R. M. Shankland, Chicago, Consulting Engineers for the contractor, but the specifications for the material and fabrication of the work were prepared by the Board.

The M. H. McGovern Company awarded the contract for building the steel tube to the Henry Pratt Company, Chicago.

CONDUIT AND WATER PIPE TUNNEL CONSTRUCTION.

As will be seen from Fig. 26, the south shaft of this tunnel was located under the sidewalk just east of the southeast corner of La Salle and South Water streets, and the north shaft was located just north of North Water Street and La Salle Avenue under the east sidewalk of the latter street. The location of the south shaft was placed outside of the roadway, as at the time the plans were being prepared the City of Chicago was preparing plans for a subway and was seriously considering South Water Street for one of the lines. Later, however, this was abandoned and the south shaft was moved just outside of the curb line, where it would cause less inconvenience to the adjacent property owners.

The location of the north shaft was fixed on the east by the foundations of a five-story brick building, and on the west by the outside wall of the foot passage of the old Street Railway Tunnel. On account of the liability of being drowned out, it was not advisable to cut into the old tunnel walls, as this tunnel was abandoned and had a direct connection with the river, so as much of the building foundation as was necessary was cut away and a steel shell ordered for the upper part of the shaft. This shell consisted of ⅜-in. steel plates 5 ft. wide, riveted together with butt joints and butt straps and battens on the inside only. All rivets were countersunk on the outside to reduce friction and prevent grooves in the clay. The cutting edge at the bottom also formed the shell for the brick lining. This lining was reduced to 9 in. in thickness, but the inside diameter of the shaft was maintained at 10 ft. The total length of shell as finally ordered was 25 ft. On October 8, 1909, the first three sections (15 feet total) had been delivered to the site, and one gang of five men completed the riveting in three days, driving some 600 rivets.

The placing of the brick lining, which consisted of the very best hard-burned sewer-brick laid in a 1:2 Portland cement mortar was completed to the full height of the shell in two days, and a platform built across the top of the shell. This platform was loaded with about 29 tons of sand bags and the shaft sunk by undermining the cutting edge. The rate of sinking was very rapid, being about 12 in. of shell with only four miners working. When the first 15 ft. of shell had been sunk, a slight cracking of the adjacent building indicated that we were not low enough to safely proceed without the aid of a further length of shell, so two more 5 ft. sections were ordered and connected up; the brick lining was placed and the shaft loaded with pig iron. When 45 tons had been placed, the shaft had sunk 8 in. without any mining. The total weight, including brickwork, platform, shell, etc., was about 94 tons, which was sufficient to sink the shaft the full 25 ft. This load showed a skin friction on the shell of about 290 lb. per square foot. When the shell had come to rest it was hung by four 1½ in. rods, extending from the shelf at the cutting edge up through the brickwork to 12 in. x 12 in. timbers thrown across the top of the shaft and firmly blocked on a solid footing. Below the cutting edge the brick lining was made 16 in. thick. As in most of the brick shafts around Chicago, the shaft was then carried down in stages of about 6 ft. at a time. The excavation was made and trimmed to the required diameter, then seven 1-in. hanger rods, threaded at both ends, were fastened to the shell and a 10 in. by 10 in. steel plate washer placed above a 4 in. sleeve nut which was recessed into the clay at the bottom of the lift. The brickwork was carried up from the washer and keyed into the finished brickwork, completed usually two shifts previous. A "collar" or recess about 4 in. deep, extending around the shaft, was cut into the clay, at the base of each section. There were usually two eight-hour shifts of miners followed by one shift of bricklayers.

The material encountered for the first 31 ft. (—31 C. C. D.) was soft blue clay easily dug with shovels; from this elevation the material began to grow harder, so that the use of picks or grubs became necessary. At —61.0 hard-pan was encountered and continued to —75.7. Between —75.7 and —83.9 there was hard-pan and scattering boulders. At —83.9 a very fine black sand was encountered and boring showed quicksand was within 4 ft. of this elevation. So the bottom of this shaft (which is the lowest part of the tunnel) was raised 2½ ft., leaving it at —83.9. This afterwards proved to have been a fortunate precaution, for borings taken about every 50 ft. showed that the quicksand followed along at about the same depth below the tunnel for its full length.

On November 5th the "eye" was turned and the driving of the tunnel began. The contractor's force was well organized and day in and day out the midnight shift drove the top heading 12 or 15 ft., the morning shift took out the bench, timbered the heading, placing such cord wood packing as was necessary, and at 4 o'clock in the afternoon the placing of the concrete lining was started. The ribs for the lining were of 4-in. channel irons bent to the required radius. Two-inch board lagging 10 in. wide and 6 ft. long were laid up as the concrete was placed. The concrete of a 1:3:6 mixture was mixed by hand at the street level, then lowered down the shaft in cars and pushed by one or two men to the face.

The material encountered in the tunnel was in general hard-pan with a scattering of boulders and occasional veins of sand and water pockets. From about the middle of the river to the south dock line there was a bed of coarse black sand in the bottom, then hard-pan and boulders to about the upper quarter of the tunnel; above this was silt and loamy clay with sand and water pockets. A vein of soft blue clay which seemed to overlie the tunnel dipped down to about the springing line of the arch every hundred or so feet, and at one place, approximately under the north dock line, this vein of clay was encountered for nearly 20 ft. This vein of clay necessitated timbering the roof continually, but as the heading was blasted out, the force of the explosion would loosen the material in the roof just below the vein of clay noted above. There were several cave-ins, but none of a serious nature except in one instance.

Referring to Fig. 26, a 7 ft. brick water tunnel crosses above the conduit tunnel near the south dock line. This tunnel was formerly a part of the City water supply system, but had been bulkheaded off at different points, pumped out, and abandoned early in November, 1909. On December 27th the contractor was cautioned about blasting until we had passed under this water tunnel. On December 30th, the face was practically under the water tunnel. The top heading had been mined out and the three holes in the bench were each loaded with two sticks of 60% and one stick of 40% dynamite. Two sticks of 40% were distributed in the face holes. The shot was fired about 9 A. M. I was at the tunnel about an hour afterward and everything looked good, although I noted that there seemed to be more material loosened than there had been with previous blasts, and also that the roof and face seemed soggy. About noon Mr. Doherty of the M. H. McGovern Company telephoned that there was a leak showing in the face. A small stream of water had showed itself about 11 o'clock just east of and approximately 2 ft. above the invert. This lead rapidly increased and when I arrived about an hour later there was over a foot of water covering the tunnel invert. The heading was being timbered and packed with hay, cordwood, and bags of sand to preserve the roof, and when this was finished there was nothing left to do but let the tunnel fill with water. The leakage amounted to about 6,000 gallons of water per hour.

Subsequent investigations proved that the bulkheads built by the City were not tight and the water tunnel was filled with water. Negotiations were entered into between the contractor and the City of Chicago to pump out the water tunnel, and by building suitable bulkheads cut off this tunnel for a distance on either side of our work. These negotiations have been consummated, and the tunnel completed.

CONSTRUCTION WORK FOR THE STREET RAILWAY TUNNEL.

Early in the month of November, complaints were made by owners of property adjacent to the tunnel that the construction of the work by "open cut" would seriously interfere with the conducting of their business, and they threatened to adopt legal means to preserve what they considered their rights.

Our specifications provide, paragraph 10, that

"The work shall be done with as little interference as possible to the public, to navigation interests, and to the adjoining property," and in keeping with this provision, the contractor stated that he was willing to do all in his power, but did not know of any method to maintain the street surface except by tunneling with a shield. The Division of Tunnels had been making some studies of this question, and at a meeting of the Board, December 7, 1909, explained the result of the studies as follows:

> "The contractor had proposed carrying on the work with the aid of a steel shield, but, on account of the many difficulties which would be encountered and the trouble of working a shield through the old tunnel, it seemed that some other method might be adopted. We investigated this question and developed two plans for obviating the difficulty and maintaining traffic either in whole or in part during the construction of the tunnel. The one plan consisted in flooring over the top bracing of the excavation and carrying the roadway over the open cut. The other proposition consisted in a true tunneling method for prosecuting the work. This, in brief, consisted of sinking a shaft on the south side of the river somewhere near South Water Street, and also another shaft on the north side of the river just south of Kinzie Street and prosecuting a main drift at the elevation of the invert of the new tunnel southward from the south shaft and northerly from the north shaft. (As the work from both of these shafts would be similar, I will describe only that on the south side.) This main drift would be extended from the shaft as far south as it was deemed possible to carry on the tunneling method. This drift would be solidly timbered and would afford a means of taking care of all excavation as the tunneling was prosecuted. At different points, say, for instance, 30 ft. apart, there would be side drifts leading off from the main drift, which side drifts would be excavated to the full height and a width of, say, 10 ft. This would then give an opening of some 10 ft. in width and the necessary height to complete a section of the reinforced-concrete tunnel, as called for on our plans submitted to the contractors. As it would take several days to complete each of these sections of tunnel, it would afford ample time for the concrete to be set and able to carry the load of the existing tunnel which would be brought down upon it before attacking 10 ft. adjoining any one of these first series of side drifts. By carrying on this method we would be completing sections of the tunnel as designed in lengths of 10 ft. which, in time, would complete the full length of the tunnel."

This latter method appealed to the contractors, who agreed to adopt it and the work has been carried along on this method, except south of Lake Street and north of Kinzie Street, and of course the river section, which will be described in detail later. These exceptions were necessary for two reasons:

1st. A portion of the distance comprises the open approach for temporary use of the tunnel by surface cars and

2nd. The new tunnel arch comes within such a short distance from the street surface that it would have been impracticable to attempt to maintain the latter while prosecuting the tunnel work.

Construction work on the south open approach was started in the fall of 1909. U. S. sheet steel piling 45 ft. long was driven about 3 ft. outside the line of the side walls. Working north from Randolph Street, the top tier of bracing was placed and the material excavated only sufficiently to place the second tier of bracing. By keeping the men working from south to north, it was always possible to have one section ready for setting bracing.

As the cut is about 45 ft. deep, and nearly 300 ft. long, with a width of between 42 and 45 ft. and only 12 ft. from the buildings which line the street, you will readily admit that great care had to be exercised on the work. To Mr. Max Languth is awarded the credit for designing the bracing which doubtlessly most of you have seen and admired.

All longitudinal timbers spanning the tunnel were 12 in. by 12 in., full length and butted against oak bearing blocks spiked to the wales. Oak wedges were driven between the wales and sheathing. Vertical and diagonal members were 6 in. by 12 in., as were also the longitudinal stiffeners. The wales were 12 in. by 12 in.

After the third set of bracing had been placed, the inner or Wakefield sheeting was driven with a 4,700 lb. Arnott steam hammer suspended from a small stiff leg derrick. The inner sets of bracing were then placed as previously described.

The excavating was done by means of clay knives. Three men were usually required—two men on the knife and one man to catch the "dog" and throw it into the small cars. These cars, which held about two yards, were carried along a narrow-gauge track just below the bracing to an elevator at one end of the cut. The cars were hoisted to a platform about 10 ft. above street level and automatically dumped into wagons. Later, a Carson trench machine was installed on the top series of bracing and the excavated material handled with buckets. North of the river, an overhead cable was used. The material excavated was mostly a good blue clay, although at times material both softer or harder was encountered.

The concrete was 1:3:6 below track grade and 1:2:4 for the walls and arches. This was mixed in a Marsh Capron mixer located at street level. A flexible chute from the discharge of the mixer carried the concrete directly to place in the forms. The invert concrete was placed in about 30 ft. lengths as soon as possible after the excavating was completed. The walls were then brought up in lifts of about 6 ft., so as to remove the bracing as the concrete was brought up.

Wooden forms and centers were used everywhere except in the single-bore arch, where steel I-beams bent to the required radius were used for centers.

The reinforcing consists of cold twisted steel rods. Only three sizes of rods were used and these so located that there could be no possibility of misplacing or interchanging sizes.

All vertical bars are 1 in.
All arch bars are 5/8 in.
All temperature bars are 3/8 in.

River Section:

As previously stated, the river section of the tunnel consists of a steel shell lined with reinforced concrete. These tubes do not form complete cylinders as did the Detroit design, neither is there a concrete encasement, but the two cylinders intersect and are separated by a vertical concrete wall which contains the longitudinal steel stiffening truss. The lining of the tubes varies from about 2 ft. thick at the crown to 3½ ft. in the invert. The only concrete placed outside the shell was to level off the top, and in what we call the keel.

The steel shell is 278 ft. long, 27 ft. high, and 41 ft. wide, and is made in plates 3/8-in. thick, 7 ft. 6 in. wide and about 19 ft. long. The plates are stiffened by 6 by 3½ by 3/8 in. Z-bars 56 ft. long, bent to the required radius and spaced 3 ft. and 4 ft. 6 in. Butt splices were used for longitudinal joints with straps both inside and out. All circumferential joints were lap spliced and the edges of the plates planed to a bevel and caulked.

The top and bottom plates of each bore are connected by 6 by 6 by 3/8 angles and riveted to the struts of the longitudinal truss. These struts are composed of 2 angles 5 by 3½ by 3/8 in. double laced with 4 in. by 3/8 in. bars. The gussets are 3/8 in. plates. The diagonal longitudinal bars in pairs (one on each side of the struts) are 4½ in. by 3/8 in., about 24 ft. long, and connect with six of the struts. The tubes are also stiffened by plate and angle gussets above and below the center wall at intervals of 7½ ft. The top gussets form a level surface, but those at the bottom were made with a wide angle to provide for a drainage pipe. The method of draining the tubes was changed later and this space filled with concrete.

In order to provide an even landing, a space of about 10 ft. in length of the bottom concrete or keel was made flat.

Near the ends of the tube provision was made for connection to a cofferdam by riveting side plates, or fins, with angle stiffeners, and an angle at the edge to mesh in with the Friestedt steel sheeting of the cofferdam. These fins extended down around the bottom of the tube so as to project into the bed of the trench and serve as a baffle to prevent water from following along the bottom of the structure and causing a leak in the cofferdam. A leak of this character under a head of 54 ft. would be a serious matter and is the one thing we all feared.

Within the space reserved for cofferdams, steel shafts 3 ft. in diameter connect with each tube and are sufficiently high to project out of the water when the tubes are sunk to place.

Timber bulkheads were built at each end of the tube while it was in the dry dock, and all temporary bracing was placed, as was also the concrete for the keel and for the center wall.

The weight of the steel in the tubes was about 500 tons. Approximately 100,000 rivets were driven. Before leaving this portion of the work, I wish to publicly compliment the Henry Pratt Company for the work and workmanship they did on the steel work. There was only one mistake on the whole job and that was in laying out two plates of the same kind instead of one right and one left hand.

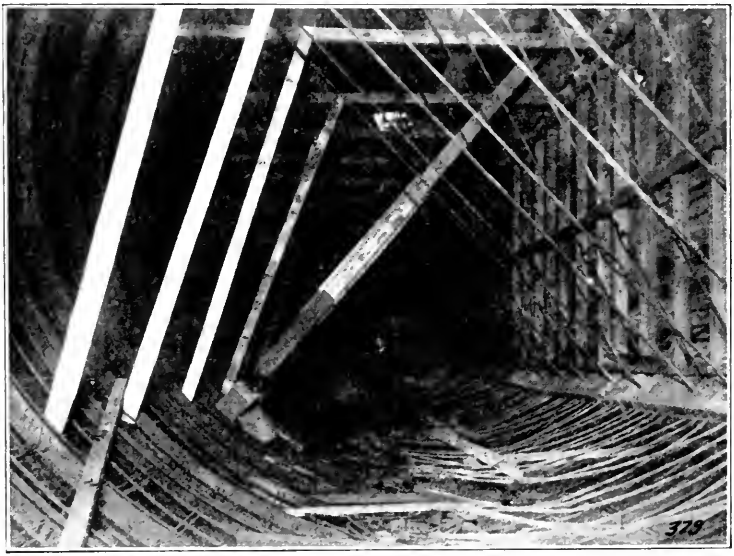


Fig. 29

The tube was erected in the Ship Owners' dry dock near Chicago Avenue and North Halsted Street. The material was either teamed or transported on scows from the Pratt company's shop, and erected by means of a derrick which traveled on a track alongside of the dry dock.

Concrete Work in Dry Dock: After the steel construction had proceeded sufficiently, a concrete plant was erected near one end of the tubes. A Chicago 1 yd. mixer was supported under a trestle work carrying a platform from one side of the dry dock to the opposite side. The material was brought from storage piles on the bank in wheel-barrows, and dumped into the mixer hopper from the platform. At the discharge of the mixer, runways led through the tubes on each side of the center wall.

The first concrete work done was the exterior section beneath the tubes. The tubes were supported on timbering about 3 ft. above the floor of the dry dock and the forms for the exterior section of concrete were supported on short posts under the tubes. The concrete was then poured through holes in the steel shell. The work of concreting the center wall was then begun and the forms were built for it so as to include a very short section of both arch and invert. The forms were carried up gradually so as to permit dumping of concrete from wheel-barrows from the runways. The runways were at first placed about 5 ft. above the bottom of the tube and later were placed about 5 ft. from the top. A view showing the center wall completed with the forms in place is shown in Fig. 29. This also shows the diagonal rods and a few of the 10 by 10 posts which were used as bracing when the tubes were floating. The end bulkheads consist of 3 by 12 in. plank, with 12 by 12 timbers 1 ft. apart behind them, and diagonal braces of 10 by 10 timbers. The joints were caulked with oakum. The tubes were floated in this condition on November 21, 1910. Its total weight was then about 3,000 tons. It was towed to a wharf near the tunnel site where the depth of the water was sufficient to permit the completion of the interior concreting without grounding the tubes.

Concreting While Floating: A new concrete arrangement was then devised for carrying on the work of lining the interior. Two 1 yd. Foote mixers were erected on platforms on the tubes at each end. The mixers were placed on rollers so that they could be used to chute concrete into the manholes of either tube. In this way the long wheel-barrow haul within the tube was limited to one-half the total length of the tube. The shifting of the mixer was a matter of five minutes' work for a couple of men. The mixers were worked alternate shifts on the two tubes, and concrete was placed at the rate of about 200 yds. in 8 hours.

The forms were placed first for a section of the invert about 5 ft. in width. This form consisted in a longitudinal bulkhead on the outside and in the forms for the steps, which were formed as a base for the cable conduits. Above this point the forms were made of 2 by 6 in. shiplap, laid over segmental rings formed by two thicknesses of 2 by 12 in. plank and shaped to the radii indicated on the plans.

The arch concrete—only a portion of which was placed before sinking—was packed in from the end of the forms, and grouting pipes were inserted vertically through this section of the lining at short distances apart. After the entire arch was placed, a grouting machine was attached to the pipes and neat cement will be forced in to fill the voids. This machine will be described later.

Excavation of Trench: This work was rendered most difficult by the depth of the water (26 ft.) and the depth of the trench (54 ft.) below the surface of the water. The existence of the old tunnel floor was also a problem. A dipper dredge was rigged up specially for the work by the Great Lakes Dredge and Dock Co. The dredge was equipped with a 2-yd. dipper bucket on a 72-ft. dipper arm and new spuds of extra length were added. It was at first thought that the dredge could excavate the trench and old invert without blasting, but owing to the length of the dipper arm and spuds, the river current, etc., this was found impractical. A drill boat containing four drills was then placed over the invert and in a period of about two weeks the invert was broken up. The material was loaded on scows by the dredge, towed out into Lake Michigan, and dumped.

Sinking the Tubes: In preparing for the sinking of the tubes—crib cofferdams were built on each end of the tubes, and the steel shafts for the manholes were built up to the level of the cribbing. This cribbing has been joined at each side by the steel sheet piling forming the balance of the cofferdam connecting the land, and the north cofferdam has been completed by filling in between the cribbing and sheet piling with clay.

The tubes were estimated to weigh about 7,967 tons when concreted and the displacement is 7,852 tons. For this reason it was necessary to leave a portion of the arch without concrete until after sinking. The tubes when ready for concrete barely projected above water. They were swung across the channel of the river and anchored by guy lines up and down stream to either shore, thus holding the tubes in position on the center line of the tunnel.

The arrangement for letting the water into the tubes consisted of a 4-pipe through the end bulkheads with branches leading to the three compartments of each tube. The controlling valves were placed at the top of the shafts. The compartments for water were three in number. The center compartment was 80 ft. long and on each side of it a 50-ft. compartment was located. The bulkheads dividing the compartments consisted of two walls of 2 in. D. & M. lumber about 6 ft. high and 6 in. apart. They were caulked with oakum and the 6-in. space between walls was filled with clay. Water was directed into the central compartment first, and into each of the other compartments accordingly, as the extra weight was needed toward either end.

Another arrangement for controlling the weight of the tubes in sinking consisted in suspending them in cables erected near each end. At each point two barges were placed on opposite sides of the tube. These barges supported a box girder 75 ft. long. At each end of each girder a small hoisting engine and boiler was placed, with cables running from the hoisting drums over the sheaves placed on the girder and down to a belt which was passed under the tube and up to the cable from the engine on the opposite side. This arrangement was calculated to handle 120 tons.

At each end of the tubes, nailed to the cribbing, were the targets placed for observation by the instrument men. A level rod was placed at each side of the cribbing and a transit target was placed on center line.

The river current was stopped by closing the gates of the Chicago Drainage Canal at Lockport and little or no interference was had on account of a current in the river. The tubes were landed upon two sets of piles which had been driven to grade in the trench, each set being about 50 ft. from the ends of the tubes. These piles were merely short pieces 3 or 5 ft. long, placed there to take the weight of the tubes until the sand could be pumped in under them, thus forming an even bearing along the entire length. The balance of the filling consists of sand and clay, leaving a thin layer over the top of the tubes.

DISCUSSION.

John Brunner, M. W. S. E. (Chairman): We are under great obligation to Mr. Artingstall for the very interesting paper that he has presented tonight. In this paper he has pointed out some of the difficult engineering problems that were met with and had to be solved in the work that he has described. In spite of all the difficulties that were encountered, the work seems to have been carried on to completion without any serious mishap or accident, and we cannot but admire the skill of the engineers and contractors who had this work in hand. The paper is now open for discussion.

Ralph H. Rice, M. W. S. E.: —I will speak briefly of the electrical features of the tunnels. The cables that go through these tunnels are the power cables that furnish current for the downtown district. The two tunnels that are used chiefly are the Van Buren Street Tunnel and the La Salle Street Tunnel. The Washington Street Tunnel, being half way between two substations, carries no cables at present except those which feed the tunnel itself. In case of the La Salle Street Tunnel, the cables are at present carried through the lower tunnel; that is, the water-pipe and conduit tunnel shown in Fig. 26. There are, I think, seventeen cables through there at the present time. When the La Salle Street Tunnel is completed, provision will be made on each side of the tunnel for 24 ducts, duplexed; that is, with a 4 in. concrete wall dividing them into two sections of 12 ducts each. These ducts will pass through the tunnel, being laid upon steps at the side of the tube as shown in Fig. 28. There are manholes placed at approximately 300 ft. intervals throughout the tunnel. Provision is made for readily connecting these ducts to those in the street; for instance, at the north end, at Michigan Street, there is a shaft left in each of the subway walls through which the ducts will pass to manholes at the surface, and then northward one block to the substation. A similar arrangement can be made at Randolph Street. In the case of the Washington Street Tunnel, the same arrangement can be made, but at present all the cables that go through are carried over the trestle work at the temporary track grade, connecting directly to manholes in the street. In the case of the Van Buren Street Tunnel, the main duct line passes out from the Van Buren Street substation and down the track grade to just under Market Street. Here there is a 5 ft. shaft passing upward to a manhole in the center of Market Street, from which large duct runs lead out. There are also ducts that pass on up on the track grade, to Franklin Street, and are there distributed. There are no particular features about these various conduit lines except that it was difficult to arrange the ducts,—to get a sufficient number through the available space and keep below the track grade. In some of them there is a change in duct arrangement at practically every manhole, but the same number of ducts is carried through the tunnel by thus changing the duct arrangement to conform to the different sections of the tunnel itself. In all cases proper drainage connections are provided to keep the ducts as free from water as may be.

The lighting of the tunnels is by arc lights suspended from the center of the roof. All lights are fed by special lighting cables from the substations so that an interruption to the power supply will not affect them.

The trolley wire is in general supported by cross spans fastened to the tunnel walls. In the double-bore sections and in the river sections where head room is limited, the common wood trough support similar to that used in subways under railroad tracks, is employed. Each track in each tunnel is provided with special feeder cables, and in all cases it is so arranged that each track may be fed from two substations. Effort has been made to assure both power and light in the tunnel at all times.

S. G. Artingstall, M. W. S. E.: The paper presented describes very fully the engineering features of the three traffic tunnels under the Chicago River, and illustrates the methods of construction and the difficulties overcome in alterations.

The original tunnel under the river at Washington Street was a constant source of trouble from the beginning. It was badly constructed with poor material and indifferent workmanship. The tunnel itself (excepting the dividing wall under the river section and roof arches in the same section) was of rubble masonry, veneered with brick. All the work was laid in natural cement mortar. The side walls of the tunnel were 5 ft. thick for the whole length, of which 1 ft. was the brick lining; under the river the dividing walls between the two roadways and between the roadways and the footway were 2 ft. thick, of brick masonry supporting semi-circular arches. These arches were 2 ft. thick at the crown, in six concentric rings, without bond between the rings. They were covered with stone flagging 10 in. thick to protect the work from being injured by dragging anchors or other cause, and were not of any structural value. From the beginning, the river section was in a very leaky condition, the water from the river coming through the roof in many places; the greater quantity came through the side walls following the joint between the rubble masonry and the brick veneering, while considerable came through at the springing of the arches. In winter time the side walls were covered by a thick coating of ice; immense icicles hung from the roof, and the roadways were covered with ice and slush. Men and teams were continuously employed to clear away the accumulation, and in severe weather the ice formed so fast that it was impracticable to keep the tunnel open, and it was closed to traffic. This condition of affairs—the tunnel being saturated with water at all times and the severe freezing in winter—quickly ruined the masonry and entailed constant repairs. By 1874-5 the river section was so severely injured as to be in danger of destruction, so the tunnel was closed to traffic, and the writer was directed to make thorough repairs of the river section.

The repairs were made by completely taking out and rebuilding the two longitudinal walls between the roadway and the footway which supported the roof under the river, cutting out and rebuilding the veneering on the side walls, and making such repairs to the roof arches as were practicable. It is evident that this work had to be done with great caution and in short sections to avoid any movement in the roof. The dividing wall between the roadways was built first; the roof being supported on strong centering, work was commenced at one of the openings which divided the wall at intervals. The masonry jamb was taken down to the invert and rebuilt 4 ft. thick with hard brick in Portland cement mortar to 12 in. above the pavement, where it formed the wheel guard. Above this the jambs of the opening were built with ashler, the stone being the mottled brown sand stone from the Lake Superior quarries. The stones were tooled on all faces and rubbed smooth on the beds to make close joints. After being dressed, all stone was thoroughly dried and seasoned and then immersed in large vats filled with raw linseed oil. No stone was used until after it had been in the vat at least 30 days. It was found that after this length of time it would absorb no more oil. The stones were full thickness of the wall, 2 ft., by 2 ft. high, and alternately 6 ft. and 4 ft. long. They were laid on a thin bed of neat cement and on top capped with a springer stone which carried the roof arches. This procedure was repeated at each opening and at the extreme ends of the walls. Following this, the old brickwork left between the opening was carefully cut away in short sections and rebuilt with hard-burned brick laid in Portland cement mortar, care being taken to assure all voids both in beds and joints being filled. The same process was adopted with the dividing wall between the roadway and the footway.

After these center walls were finished and the temporary supporting-timbers removed, the veneering on the outside walls was removed in short sections and rebuilt with hard brick in cement mortar, bonded into the rubble backing, and grouted. Great care was taken to fill voids in both new and old work, and make the work waterproof.

The masonry in roof arches was repaired and replaced as far as possible with new material, and where there were bad leaks the joints were caulked with lead. These repairs amounted to practically rebuilding the river section of the tunnel, and after their completion the leakage was so slight that it caused no serious inconvenience, and the section remained in good condition until removed to admit of lowering the bed of the river. Later on, the retaining walls at both the east and west ends became so weak as to be in danger of falling in, and they were taken down and rebuilt, but no special engineering features were needed in the execution of this part of the work.

The Author: Referring to the section which we term a high wall section, see E-E Fig. 24, my recollection is that the distance from the base of the foundation to the top of the parapet is, at the maximum, about 48 ft.; as stated, it is the highest reinforced-concrete wall that has ever been built. We could not make it very thick, neither could we adopt a cantilever design, for with that construction we would have had to come back somewhere to the building line, which was impracticable, so we introduced struts in the wall at about mid-height and others near the top. These would not give us stability, so we introduced a heel at the berm between the inner and outer line of sheathing; that is, about 20 ft. or so below the surface. It was the intention to get a heel as shown in Fig. 24, but the railway company's inspector made an error in alignment which cut off about 4 ft., so we had to redesign all these walls, accepting the conditions just as the sheeting left them, which made a rather complicated design. You will note, also, that the inside of the walls overhang the tunnel, which is out of the ordinary. If we had brought the inside face up straight, we could have made a better design, but La Salle Street is only 80 ft. wide, has two 12 ft. sidewalks, and the Commissioner of Public Works insists on having two 16½ ft. roadways, which is narrow enough, anyway. This gives an overhanging wall with the radius of the overhang the same as the radius of the single-bore tunnel. It presents a rather strange appearance, but it handles the design very nicely and is a little more economical from a construction standpoint, because—at least in making our estimate—we figured that the centers on the single-bore arch would not be in service long enough to be entirely destroyed or in such condition they could not be used any more. So we carried that curved construction right along in the open cut, thus enabling the contractor to use his centers until they were worn out. This resulted in quite a saving in time and money to both the contractors and the company.

I would ask Mr. Kelker his opinion in regard to track and ballast in tunnel construction. There has been considerable discussion whether or not to ballast track in tunnels. I always say ballast, because personally I think the track ought to be ballasted, but others are not of this opinion.

Mr. Kelker: There is little to say about the track. It is merely track, well laid, well ballasted, and we hope it will give the life it should and perform the function for which it is built. It is not different from any other track in the country.

In regard to ballast, I take it that Mr. Artingstall refers to the often discussed point of the economy in the use of the two classes of track construction; that is, track construction with a rigid foundation, and that with a ballast foundation, which compares with the steam road construction. While it is difficult to know in every case which is the best, yet it would seem that where we have an adequate sub-grade the ballasted grade presents certain economies in maintenance and in life that we cannot get from a rigid track; when, where the sub-grade is poor, we can protect our track construction and increase its life because we cannot hope to maintain ballast for any period of time, as it will sink into a poor sub-grade. On those two considerations practically hinges the selection of the track construction. Personally I believe that the ballasted track, with a reasonably good sub-grade, is more economical, and while not any cheaper in construction, yet it results in economy in maintenance and in renewal. It is extremely difficult to obtain an absolutely rigid track, as we have frequently hoped to have had in various cities, and the only city I know of personally, where track construction on concrete is rigid, is Philadelphia, in their subway and on a few of their streets. They have been enabled to obtain this desirable feature of the rigid-track type by a great deal of care and inspection, watching over the use of the materials and the actual work in the field, (this is very hard to give where we have a great amount of track to lay); in other words, close, personal, intelligent supervision. So that it is almost a toss-up if one takes all considerations into view, and yet where we have a concrete invert which is permanent and well laid, and on a good grade where the drainage has been properly cared for, I think that the ballasted track will answer every purpose that a track with a concrete foundation would furnish; in addition, it is easier to handle and easier to keep in the proper condition for traffic.

CLOSURE.

The Author: In preparing this paper for presentation to the Western Society of Engineers there was not sufficient time at my disposal to bring the subject matter up to date nor to go into details, consequently there are several omissions which should be called to your attention and made a matter of record. These additions will not be taken up in chronological order, but will be explained from the few notes which I have made as they came to me in the past week.

As the Washington Street and the La Salle Street Tunnels were originally built by the City under public property, all work on these two tunnels had to be done with the approval of the Commissioner of Public Works, and the ordinances have always been very specific on this point; consequently before any work could be performed, the plans and specifications were approved by the City Engineer, who kept an inspector on the work, reporting direct to the City Engineer's office.

Upon the acceptance by the Chicago Railways Company of its ordinances of February 11, 1907, the direction and supervision of the tunnel work came under the jurisdiction of the Board of Supervising Engineers, which was established by the above ordinance to take charge of the rehabilitation of the surface railways of the City of Chicago. This Board—composed of Mr. Bion J. Arnold, Chairman and Chief Engineer; Mr. George Weston, Assistant Chief Engineer, representing the City of Chicago, and Mr. John Z. Murphy, representing the Chicago Railways Company, and Mr. Harvey B. Fleming, representing the Chicago City Railway Company—established the Division of Tunnels which, with the writer in charge, completed the work on the Van Buren Street Tunnel, then prepared the plans and specifications for the reconstruction of the Washington Street and the La Salle Street Tunnels, and such other work as remained to be done on the Van Buren Street Tunnel. The work which is now being done for the Chicago Railways Company is under the direction and supervision of the Board of Supervising Engineers, acting through the Division of Tunnels.

Shortly after the awarding of the contract for the reconstruction of the La Salle Street Tunnel, Messrs. James A., Robert, and Charles Green purchased the controlling interest in the M. H. McGovern Co. and have since then carried on the work. Mr. Max Languth is superintendent for the contractor. To him is given all credit for the solution of the numberless difficulties which have confronted the contractor, for the ingenious and economical methods of prosecuting the work, and for the kind consideration which he has given to our suggestions.

As previously stated, there are several omissions in this paper, but the writer will not attempt to more than call attention to the interesting tests, the method of stopping leaks in the Washington

Street Tunnel, and finally give a short description of the work at La Salle Street—either completed subsequent to the sinking of the steel tubes for the river section, or now in progress.

In one of the previous paragraphs it is stated that the Washington Street Tunnel structure was completed in January, 1911. This is not entirely correct, but the work was sufficiently advanced to permit the operation of street car traffic. At this time there were numerous leaks through the tunnel walls, which under the terms of the contract had to be absolutely water-tight. Geo. W. Jackson, Inc., has at this time a force of men engaged in this work, and as the method seems to be effective, a description of the apparatus and process employed might be interesting.

A grouting machine, air compressor, electric motor, and small derrick mounted on a flat car belonging to the Chicago Railways Company are run down into the tunnel after midnight.

The machine (manufactured by Cockburn Company of Jersey City, N. J.) consists of a drum into which the cement and sand are placed and the cover clamped down. Water is then admitted and the mass agitated by means of paddles mounted on a shaft, one end of which, extending through the drum, is fitted with a belt connected to an electric motor. A 2-in. hose is connected to a valve in the lower side of the drum and leads to the connection at the grouting pad.

Where a perceptible amount of water is coming from one spot, the hole is cleaned out and enlarged to about 2 in. diameter; a felt gasket is then placed around the hole and the flange of a 5 in. pipe placed over the opening. The grout is forced through a 2 in. pipe fitted with a tee (capped at one end) which is fastened into the 5 in. pipe. This 5 in. pipe is used only to hold the pad tightly in place and has a jack screw fitted in one end for bracing against the opposite wall.

The amount of grout forced into the hole depends on the size of the hole to some extent, but some leaks take a large amount of cement. The pressure (about 110 lbs.) is not kept on continually, but by applying it for intervals of five or ten minutes with a rest of about the same amount of time, grout can be forced into the leak at practically every trial. The pad and jack are left in place until it is necessary to remove them for the first cars passing through the tunnel at 5 A. M.

Tensile Tests of Reinforcing Rod Lap Joints.

In connection with the method previously described for carrying on the tunnel work at Washington Street, it was necessary to use splices in the vertical reinforcing rods at the various drift levels. This is shown on the tunnel section C-C, Fig. 21. As it was not deemed prudent to rely entirely on the bonding strength of the concrete to transmit the stress from one rod to another, tests were made on 1-in. twisted steel reinforcing rods spliced with clamps.

These test splices consisted of one or more simple "U" clamps securing the over-lapped ends of the rods; the whole then being placed under tension load was applied at a rate of 1,000 lb. per minute. As the keys left in the concrete face of each drift allowed a minimum of 8 in. over-lap, this length of splice was used in the testing of the effect of—

1st—A single clamp.

2nd—Two clamps fastened on opposite sides.

3rd—Three clamps—two applied from one side and one from the opposite side.

The results showed that the second type was in general the best to use in construction work. This type, when the clamp was tightened enough to slightly bend the plate, showed no movement up to a resistance of 6,400 lb., at which load there was a slip of ⅛ in. When put under further load there was no movement until the stress reached 13,690 lb., when there was a sudden slip of 3/16 in. in the strap of one of the clamps and ⅛ in. slip of the rods. The rods then began to pull apart at this or a lower stress. The single clamp allowed the bars to move practically as soon as any stress was applied, and showed a slip of ⅛ in. at 4,000 lb. stress, increasing to ¼ in. slip at 5,600 lb.

With three clamps, there was a slip of ⅛ in. on the bars with a stress of 6,760 lb. At 10,730 lb. one of the straps started to move, another started at 11,690 lb., and the third started at 18,330 lb. The total slip at this time was ½ in. At 25,580 lb. there was a sudden slip of the bars and one clamp became entirely loose, so that no further load was applied.

The designs were based on a unit stress of 16,000 lb. per sq. in. in the steel, and the tests showed that the clamps were good for about 7,000 lb. up to the first slip, which was always a sudden one of ⅛ in. Assuming that this resistance would be increased when the rods were embedded in concrete, it was decided to use a splice of the second type, and rely on the bonding stress of the concrete to supply the deficiency between the resistance of the clamp and the stress in the steel. In the various drift levels the key was about 12 in. in depth, which assured a minimum of 8 in. over-lap, as previously stated. This made it a fairly easy matter to apply the clamps in position. The writer believes that the resistance of the splice would have been greatly increased by the use of a plate with corrugations approximating the twist in the bars, which would have given a greater bearing area between the plate and the bars.

La Salle Street Tunnel.

The original intention was to waterproof the tunnel structure and retaining walls with brick laid in asphalt mastic, but as there was so much delay caused by this method, the contractors requested a change to an integral waterproofing which could be mixed directly with the concrete. They submitted samples of different compounds which were subjected to various tests, when mixed with concrete made under normal working conditions.

The results of these tests showed that while some compounds were fairly effective as a waterproofing, they had a very deleterious effect on the strength of the concrete. The compound used fulfilled the requirements for waterproofing, and had no ill effect on the concrete. In fact, the tests at that time and all subsequent ones, which have been very numerous, show that the resulting concrete has nearly one and a half times the crushing strength of plain concrete of the same proportions.

After the sinking of the steel tubes for the river section, two lines of Friestedt steel sheet piling 65 ft. long were driven so as to connect the crib (which was built across the steel tubes) with the single rows of sheeting extending out from the land sections, thus forming a double cofferdam across the tunnel and parallel to the dock lines.

The method of making this cross dam tight and filling the space under the tubes was unique and effective. First, all the slush and soft mud which had settled into the trench subsequent to the dredging was removed by means of a 6 in. centrifugal pump. Then several 2 in. pipes 60 to 70 ft. long were placed so as to terminate at different distances under the tube, and at different elevations above the bottom of the trench, after which the space between the sheeting and tube was filled some 5 ft. in depth with crushed stone, and a pneumatic mixer was used to force grout through the pipes until all the voids in the pocket on one side of the tube were filled. The mixer was then connected with each pipe in the other pocket and the operation repeated. When no more grout could be forced through the pipes, the crib and pockets were filled with clay puddle.

The grouting machine used on this work consisted of a covered cast-iron cylinder, funnel-shaped at the bottom, tapering off to fit a 6 in. pipe. The top was fitted with a hopper for the materials and separated from the mixer proper by an air-tight valve. When the hopper was emptied, this valve was closed and compressed air admitted at both the top of the chamber and the junction of the latter with the 6 in. spiral riveted discharge pipe. There was no machinery in the mixer but the grout was discharged a perfect mixture. The theory of the inventor of this machine is that the material is mixed with air to about double its volume, and friction on the pipe retards the outer layer of the mass while the central portion, advancing more rapidly, spreads out, comes in contact with the pipe, is slightly retarded by friction, and is caught or passed by a new central portion, which in turn travels in advance of the outer portion, so retarded, and so on till the whole mass is discharged in place.

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The experiments with different mixtures, of varying consistency—from water to absolutely dry materials—showed that there was no perceptible variation in any part of the batch. Even cement bags were shot through the mixer and were discharged twisted and disarranged. Compression tests showed a strength equal to a batch mixture, so it was decided to use this machine for completing the arch in the river section of the tunnel. For this purpose the mixer was placed on the north cofferdam and a pipe led down into the "steel tubes" to the point of discharge. The maximum distance was about 300 ft. from the mixer and 30 ft. below it. About two batches of 6 cu. ft. each were discharged in place every five minutes, or approximately 10 cu. yds. per hour, with ten men. This was a very small mixer. in fact, it was built only for experimental purposes, but it is certainly a wonder, and if built in commercial sizes will be instrumental in greatly lowering the labor cost of concrete.

After the river portion of the cofferdam was puddled, the question arose as to how to brace the single steel sheathing forming the sides of the dam. It would have been dangerous, if not disastrous, to attempt this in the usual way of framing the top tier of bracing on the surface of the water, then lowering the water a few feet and framing the second tier, and so on; for a depth of 58 ft. on the outside with a varying depth inside would have given a different hydrostatic pressure on either side of the sheathing and resulted in "a couple" with nothing to resist it.

A diver carefully measured the distance between the sides of the dam for each 6 ft. in depth at each point where a brace was to be located. It was found that the dam was clear of obstructions to 30 ft. below the water surface. With the measurements as a base, a tier of bracing was framed which would fit at —30. This was then sunk 4 ft. and the next set of bracing framed and sunk. The next tier was then framed complete and sunk, and so on until six tiers of bracing had been completed and submerged to its proper place. The diver then securely wedged each set against the sheathing, and when the water was being pumped from the dam the necessary additional wedging and backing was performed. The bracing below —30 was placed in the usual manner of lowering the water to the required depth, framing the timbers, then pumping, and excavating if necessary, to the next depth and so on.

Before leaving this subject, the writer desires to mention that this is the deepest cofferdam built in this country and the open cut section is the largest and deepest open cut section ever known.

At this time the tunnel is about three-fourths completed, the connection between the land section and north end of the river tube has been successfully accomplished, and the south connection is almost ready to be made. There is every prospect of the completion of the work early in 1912.

Subway Connection.

It is clear from a study of the foregoing paper that in perfecting the designs for the two river tunnels, Washington and La Salle Streets, ample provision has been made for the use of these tunnels, not only to accommodate present surface-traction lines, but also ultimate rapid-transit subway lines. This step was considered imperative, as the ordinances of 1907 under which this work was carried out compelled such construction and plainly contemplated the early establishment of a comprehensive rapid-transit subway system for Chicago. In establishing the permanent grades of both tunnels, consideration had to be given to the existing or probable future location of the tunnels of the Illinois Tunnel Company, the ordinance for which provides that "the highest portion or top of the crown of any such tunnels or conduits shall be located at a depth of not less than 19 ft. below Chicago City Datum." At the terminals of the Washington and La Salle Street Tunnels this would establish a distance of 33 ft. between street level and the highest part of the Illinois Tunnel. This condition practically fixed, within a small range, the elevation of the subway rail below the street surface, which by careful designing was reduced to 31 ft. Another condition contemplated the possibility of an underground trolley system for the surface lines. However, if this latter consideration was omitted from the design, the saving in height could be applied in increasing the headroom in either or both subways.

A very complete design was made for such a crossing with the elevation of the low-level rail at about —19, which affords a proper connection with the permanent track grade in the tunnel previously noted. This design provided for either island or side platforms (assuming that a station was located at the crossing), and gave a clear headroom of a trifle over 14 ft. in each subway.

ACKNOWLEDGEMENTS.

Through the courtesy of the Chief Engineer of the Work, the drawings and accounts of tunnel operations detailed in the reports and records of the Board have been freely drawn on and the records of the last two years' work quoted from forthcoming reports of the Board.

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PERMANENT INTERNATIONAL ASSOCIATION OF NAVIGATION CONGRESSES.

This Congress has not hitherto been held in the United States, and consequently its objects, characteristics, and methods are not generally known in this country.

As the preparations both here and in the forty other countries supporting it are now going forward actively for its triennial meeting in Philadelphia about June 1st next year, a résumé of the work of the Congress will be of general interest, especially now when our own country is engaged in many important works and projects of navigation, and also now that we are interested more than formerly in maritime development in other countries, to whom we send our products and from whom we receive theirs.

The removal of obstructions to the free movement of commerce, the amelioration of interior waterways, the construction, maintenance and operation of canals, both inland and maritime; the protection of navigation by lights, buoys and beacons, the facilities for handling cargo, the relations between rail and water transportation,—these are the general questions which the International Navigation Congress discusses and for which preparations are now being made.

It has too often been the case in congresses and annual meetings and conferences in this country on various subjects that occupy public attention, that the procedure consists of the reading to the congress of long and often tedious papers, or speeches are delivered, often discursive and filled with irrelevant matter, which weary the audience, consume valuable time, and leave little opportunity for discussion, and even that often suggested at the moment of listening to the papers or addresses. If good stenographers are present and there is money in the treasury for meeting the expenses of publication, the literary result is a mass of matter in ponderous volumes that fill up the shelves of libraries for later reference but rarely utilized.

The founders of the navigation congress did not fall into this unwise and useless way. They realized from many years of experience in the two separate congresses—maritime and inland—that, when these two became united into the International Navigation Congress, business methods must be provided for at the outset in order to make the congress eminently and practically useful. It conceived the idea and carried it out of first obtaining the support of nearly all the governments of the world and committing them to the work of the congress by annual and continuing appropriations, by national committees appointed by these governments, reporting to the permanent commission at Brussels, the general office of the congress, and all working in accord for a definite purpose. That purpose is the dissemination to all the countries of the results of the experience of each in its navigation works. The founders of the congress—in 1898, when at Brussels the two congresses, maritime and inland, came together after a resolution to do so at the Hague four years previous—adopted a method of procedure eminently practical and useful to navigation.

The subjects to be treated by reports and communications at each congress are selected with care by the permanent commission at Brussels in correspondence with the national committees, two years in advance of a congress. This selection is made at an annual meeting of the government delegates of many countries. These subjects, put into the form of questions and communications, are sent out to all the countries of the world, where, through the national committees, writers are selected, one for each special subject. The papers must be in the hands of the Permanent Commission at Brussels at least a year in advance of the opening of the congress, which is held in some one of the countries interested. The last one was held at St. Petersburg, the one previous at Milan. These papers are translated into the three languages of the congress,—French, German, and English. They are then sent out to the entire permanent membership and also to all temporary members of the forthcoming congress.

In the country where the congress is to be held, general reviewers are selected for each question and subject for communications. These reviewers study the papers carefully, make a brief digest of them, and give their own views as well, founded on the consensus of opinion of the experts who have written the papers and on their own experience. They also give their views as to what "Conclusions" should be adopted by the congress on each subject.

The reports of these general reviewers are also sent forward to Brussels, where they are translated into the three languages and follow the papers previously distributed to all countries, in the form of a convenient booklet, all general reports being bound up together for convenient use at the congress.

It will be seen from this résumé of the methods that when the members assemble at the congress they are prepared, from previous reading of all the papers and the reports of the general reviewers, to get right down to business in the meetings. The congress separates for its sessions into two sections—inland and maritime. The papers are never read—they have been studied long in advance of the congress—only the suggested conclusions are presented, which are discussed, generally modified, sometimes entirely changed, edited and put to vote, paragraph by paragraph, often sentence by sentence, until out of it all comes a definite, clear, very precise opinion of the experts of the world.

It can be readily understood that these conclusions become effective in guiding not only governments but the inland and maritime navigation interests of the whole world into correct methods to conform to the ever increasing requirements of navigation.

The Philadelphia congress will not be behind its predecessors in practical and up-to-date subjects. Some of them are as follows:

Improvement of rivers by regulation, dredging, and reservoirs. Dimensions of inland canals for heavy traffic, including operating and dimensions of the locks. Intermediate and terminal ports, best methods of combining, facilitating and harmonizing transfers between the waterway and the railway. Application of reinforced concrete to hydraulic works. Protection of banks and how to utilize shallow rivers.

The above relate to inland navigation. When we come to ocean navigation we also find subjects of great and pressing interest to all maritime countries:

Best means of docking and repairing vessels. Dimensions to be given to maritime canals considering the probable dimensions of sea-going vessels of the future. Mechanical equipment of ports. High-powered dredges and the removal of rock under water. Reports on the most recent maritime works at the more important seaports, especially relating to breakwaters. Applications of reinforced concrete and its preservation. Bridges and ferries,—tunnels under maritime channels. Safety of navigation,—lighted buoys.

The members of the Western Society of Engineers will appreciate immediately the vast usefulness and extended influence of the International Navigation Congress, not only upon inland and maritime navigation elsewhere, but especially in this country and particularly at this time. There has not been for two hundred years as much general and special interest in the United States in navigation as at this period in its history. This eminently useful congress could not have come to this country at a more opportune time. Let us see what we are doing in matters to be discussed by the forthcoming congress.

The state of New York is in the very midst of its great inland canal construction, to cost over $100,000,000. It is now discussing the extremely important subject of intermediate and terminal facilities, particularly at the port of New York.

The Federal Government is soon to throw open to the navigation of the world the Panama Canal. Important questions are now before the country respecting its terminal facilities.

The Cape Cod Maritime Canal, to shorten the distance between points south and north of it and give navigation a safer route, will be more than half completed.

The various waterways associations of the country are interested in coast-wise navigation and in the development of navigation on the Great Lakes. The Mississippi, Missouri, and Ohio systems of navigation, are discussing great questions which are embraced in the list of subjects for this Congress.

The United States Congress and the War Department are engaged in vast works of inland and maritime navigation, and then there is now to the front the general and very important subject of the possible correlation of waterways and railways, in which are interested not only the advocates of inland navigation but far-seeing railway managers, for they appreciate the extraordinary growth of our manufactures, products of agriculture, and population, which makes it impracticable for the railways to conveniently handle and transport the bulky products of the country.

The navigation congress is solving these great problems for the entire world, in respect to all the systems of inland and maritime navigation. It is setting the pace in all countries in these very important and practical matters.

It is a part of the program to show the members from other countries many of our works, and these conditions, above enumerated, will be brought to their attention on the inspection trips, such as the terminal conditions at the ports of Philadelphia and New York, the proposed Atlantic Coast waterways, the barge canals of New York, the port facilities and terminal equipment of the Great Lakes ports between Buffalo and Chicago, via Sault Ste. Marie, and the movable dams of the government on the Ohio River. It is hoped to arrange for a special trip to the Panama Canal, which is of world-wide interest to hydraulic engineers and navigation men.

The Congress of the United States several years since enacted legislation (approved June 28, 1902), appropriating annually $3,000.00 for the navigation congress, $1,000.00 of which is sent to Brussels to assist in the general support of the work of the Permanent International Commission. Our government now has seven members on this commission, which constitute the American committee, now engaged in preparing for the Philadelphia congress. Congress has appropriated $50,000.00 for it, and the state of Pennsylvania $25,000.00.. The city of Philadelphia is preparing amply to receive and entertain the members. The financial and social success of the congress is thus assured.

The commercial associations along the route of the trips of inspection of the most important works, on rivers, canals and harbors, are preparing to receive the members of the congress and give them an opportunity to examine their commercial works.

It is the custom in European countries to present to the visiting members souvenirs describing and illustrating the more interesting features of the cities visited and their commercial undertakings.

As a member and past-president of the Western Society of Engineers, the writer makes the suggestion that steps be taken not only to secure a large membership of the congress from the society but to unite with the Chicago Association of Commerce in receiving the members of the congress and presenting them with a descriptive and illustrated pamphlet of the city and its interesting navigation facilities. This would be a welcome souvenir to take to their homes in other countries as a reminder of your hospitality and progress.

The success of literary features of the congress is also assured, for some of the most competent engineers and navigation men of the world have written papers on all the subjects to be discussed, and many of them will be here to discuss them.

There are two classes of membership,—permanent members, whose dues are $2.00 per annum, and temporary members, that is those who desire to attend and receive the papers of any one special congress, and whose dues are $5.00, but they may be later transferred to permanent membership by an annual payment of $2.00.

It should be stated as general information of interest that this congress is a continuing institution, engaged in not only publishing the literary product of its triennial congresses but also intermediate papers and reports of interest, which are distributed to the entire permanent membership, which now numbers over 2,000, found in forty-three countries.

Sept. 11, 1911. E. L. CORTHELL.

PROCEEDINGS OF THE SOCIETY

Minutes of Meetings.

Extra Meeting October 25, 1911.

A joint meeting of the Electrical Section W. S. E. (No. 759 of the Society) and of the Chicago Section, A. I. E. E., was held Wednesday evening, October 25, 1911.

As this was the annual "Steinmetz Meeting" when there is always a large turnout, the meeting was held in the Fullerton Memorial Hall, Art Institute.

The meeting was called to order at 8:15 p. m. by Mr. J. G. Wray, who presented Mr. Bion J. Arnold, Past-President of this Society and also of the A. I. E. E., who in his turn introduced Dr. C. P. Steinmetz.

Dr. Steinmetz took as his subject "Reactance in Alternating Current Circuits." After the address a couple of questions were propounded which the speaker for the evening answered at some length.

There were about 460 in attendance. The meeting adjourned about 9·45 p. m.

November 1, 1911, was the evening for a regular meeting which, however, was not held, as Judge J. C. Davis, of Des Moines, Iowa, who was to have addressed the Society, was prevented from coming to Chicago at that date.

Extra Meeting November 8, 1911.

An extra meeting of the Society (No. 760), a meeting of the Bridge and Structural Section, was held the evening of Wednesday, November 8.

The meeting was called to order about 8:20 p. m. with Mr. John Brunner, Chairman, and about 120 members and guests in attendance.

There was no business before the Section so Mr. Albert Reichmann, M. W. S. E., was presented, who read his paper on "Structural Steel Design."

Discussion followed from the Chairman (Mr. Brunner) and Messrs. J. M. Johnson, A. F. Robinson, Andrews Allen, W. C. Armstrong, F. E Davidson, F. W. Dencer, Karl Hellenthal, and Mr. Von Hoff

The meeting adjourned about 10:15 p. m.

Regular Meeting, November 15, 1911.

A regular meeting of the Society (No. 761), postponed from November 1, 1911, was held Wednesday evening, November 15, 1911.

The meeting was called to order at 8:20 p. m., President O. P. Chamberlin presiding and about 80 members and guests in attendance.

The reading of the minutes of the preceding regular meeting, October 4, was dispensed with by consent, as they had been published in the Journal.

The Secretary reported from the Board of Direction that the following had applied for membership:

Fred E. Amthor, Gary, Ind.
Fred H. Burgess, St. Louis, Mo. Transfer.
Willis G. Frost, Fort Atkinson, Wis.
Edwin J. Fowler, Chicago.
Robert C. Schwarz, Chicago. Transfer.

Also that the following had been elected into membership:

Henry H. Hindshaw, Rogers, Mich	Member
Charles L. Armsby, Chicago	Associate Member
Albert L. Wallace, Chicago	Junior Member
Charles R. Richards, Urbana, Ill	Member
Robert V. Howard, Oak Park, Ill	Junior Member
Edward A. Green, Chicago	Member

The Secretary also stated that plans were under way for the Annual Meeting to be held the two days of January 10 and 11, 1912. It was proposed to make an excursion to the McCormick Harvester Works on 26th street in the afternoon of Wednesday, January 10. The regular Annual Meeting of the Society and banquet would be held that evening in the building of the University Club on Michigan Ave. The next day, Thursday, January 11, it was planned to have an excursion to Gary, Ind., to visit the plant of the American Bridge Co. and perhaps some other places of interest near by or perhaps a visit to the car works at Pullman. A "Smoker" would be held that evening in the Society Rooms in the Monadnock.

There being no other business, President Chamberlain introduced Judge J. C. Davis, of Des Moines, Iowa, who read his very scholarly paper on "The Relation Between the Railroads, as Common Carriers, and the State and Federal Government."

Discussion followed from President Chamberlain, W. E. Symons, and W. L. Abbott, with replies and closure from Judge Davis.

Mr. G. T. Seely moved a vote of thanks, which was carried unanimously.

The meeting adjourned at 10 p. m.

J. H. Warder, Secretary.

BOOK REVIEWS*

Framed Structures and Girders: Theory and Practice. Vol. 1. Stresses. By Edgar Marburg, C. E., Sc. D., Professor of Civil Engineering, Univ. of Penn. McGraw-Hill Book Co., New York; 1911. Cloth; 6 by 9½ in.; pp. 540. Many illustrations. Price, $4.00 net.

This text-book treats very clearly and accurately the derivation of the fundamental principles of statics applicable to the subject, the determination of shears and bending moments in beams, and the analysis of simple roof and bridge trusses resting on two supports.

The work will be found useful and valuable as a reference book since the treatment of each subject is complete, and every principle involved or mentioned is, by cross-reference, made readily accessible, and the cross-references will greatly facilitate the use of the book to an occasional reader.

The examples given in detail and the demonstrations are in general the simplest and most direct that could be employed. There is evidence that care has been taken that academic methods were not overdone to the exclusion of common and practical methods used in ordinary office practice. Where several methods have been given, notation has been made as to the adaptability of same to various usages.

This work is to be commended particularly upon its very clear and precise definitions, which never leave one in doubt as to the meaning of the subject treated. Statements in regard to relation of shear and bending moment are plainly made, and give one a satisfactory grasp of the subject. The development and use of shear and moment diagrams is very completely worked out, and leaves nothing vague or in doubt in the matter. Throughout the work the discussions on use of various methods are clear and convincing. The author seems to have no pet hobby of his own which he wishes to foster and put off on his readers as having special merit or worth not its own.

The historical chapter is of especial value, being concise, exact and brief, and is well worth studying. The facts contained should be in the memory of every engineer.

The form, workmanship, and printing of the book is excellent. The section headings, sub-titles, and italicized parts aid very materially in finding important matter. The free use of diagrams anl illustrations makes

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*The books and pamphlets noted in these reviews are in the library of this society.

the work quickly and easily comprehended, even if the method is unfamiliar to the reader. There are very few typographical errors, and as this is the first edition, it shows the result of very careful editing and proofreading. The drawings, diagrams and cuts have been well executed.

The completeness of the work and its modern methods should be all the recommendation necessary for the work to find a place in the library of the engineer not already having works covering the same field of engineering.

The reviewer, in reading this volume, feels that he has gained by so doing.

The division of the subject so as to have it appear in three volumes is worthy. The field covered in this volume is complete in itself.

S. T. S.

STRENGTH OF MATERIALS. By H. E. Murdock, of the University of Illinois. New York, 1911. John Wiley & Sons; 5 by 7½ in., 308 pages, many illustrations. Cloth bound. Price, $2.00 net.

It is the primary purpose of this work to present the fundamental principles of the strength of materials without the formal use of the calculus, and, moreover, to cover all parts of the subject. Such parts as the deflection of beams, strength of columns, horizontal shear, combined stresses, and impact loads are usually omitted in works that do not use the calculus treatment, and this comprehensive work will doubtless be of value to a large class of students and practicing engineers.

The treatment of the subject is somewhat brief, the evident purpose being to present the derivation of principles and formulas in a clear and concise manner, to give the student a clear comprehension of the principles involved, rather than to go into the details of elaborate developments. The ground covered is that usually covered in a college course for engineering students. A large number of illustrative examples and problems are given for the purpose of making clear the application of the theory. While the subject generally is developed without the aid of the calculus, one chapter is devoted to the derivation of the elastic curve of beams by means of the calculus method.

To readers who prefer graphical methods this book will prove particularly interesting. There is one chapter given to graphical integration as applied to the determination of the deflection of beams. Aside from the practical value of this method it possesses the advantage of showing the physical meaning of the constants of integration. In the algebraic developments, as well, an attempt is made to give the student conceptions of the physical meaning of the different functions rather than to treat them as mathematical symbols. The book contains a great many illustrations, and a number of tables relating principally to properties of materials.

J. E. M.

THE TESTING OF ENGINES, BOILERS, AND AUXILIARY MACHINERY. A Treatise on the Construction and Use of the Instruments and Methods Employed in the Testing of Prime Movers in the Laboratory and Workshop. By W. W. F. Pullen, Whitworth Scholar; M. I. M. E.; A. M. I. C. E. Second ed. The Scientific Publishing Co., Manchester, Eng. Cloth; 8½x5½ in.; pp. 730; 733 illustrations in text. Price, 12 shillings, 6 pence net. (American price not stated.)

Professor Pullen has evidently fingered with pleasure the pages of many instrument catalogues before preparing this book. The result is a treatise on appliances for testing, rather than on testing. The testing of prime movers occupies a secondary position compared with the testing of the testing apparatus, in the opinion of the distinguished author.

There are twenty-three chapters, as follows: Tables and other data. Mechanical aids to calculation. Measurement of Pressure, Temperature, Speed, Power Output, Power Input with Dynamometer and also with Indicator. Indicator Rigs and Accessories. Management of Indicators. Steam

Engine Indicator Diagrams. Adjustment of Slide Valve. Internal-combustion Engine Diagrams. Testing Indicator Springs. Measurement of Quality of Steam and Quantity of Steam and Water. Testing of Steam Engines, Boilers, Auxiliary Machinery and Internal-combustion Engines.

The book is encyclopedic and has more value for reference purposes than as a handy manual for the practical engineer. It has probably been prepared as a help for instructors in testing laboratories of engineering schools. E. McC.

THE DESIGN OF WALLS, BINS AND GRAIN ELEVATORS. By Milo S. Ketchum, C. E., University of Colorado. Second Edition, New York, 1911. McGraw-Hill Book Co.; 6 by 9 in.; 556 pages. Many illustrations, diagrams and tables. Cloth bound, $4.00.

The second edition of this book is now on the market. The author has brought together in this volume a large amount of valuable information on the subjects named in the title, dividing it into three parts.

In Part I, several authorities are quoted on the action of earth pressures on walls, followed by formulas and designs for a great variety of retaining walls, with methods of construction and cost.

In Part II, the author takes up the subject of bins for the storage of coal, sand, ore, etc., with examples of several installations, tables of pressure, graphic description of stresses in hoppers and frame work, also method of handling this class of material.

In Part III, a subject is taken up (grain pressures in deep bins and elevators), on which up to the time of the appearance of the first edition of this book, nothing had been printed with the exception of a few pamphlets and papers, which were prepared to be read before engineering societies. A paper of this nature was read by Mr. James Macdonald, before this society some years ago.

The information contained in Parts I and II will be found of value to engineers in general, while that contained in Part III will be of exceptional value to that class of engineers who make a specialty of the design and construction of grain elevators, for in this book practically all that has been published on this subject is gathered together, also the results of experiments made to determine the action and pressure of grain in deep bins. Those made by Mr. J. A. Jameson in 1900 are given considerable space. G. R. W.

ROCK MINERALS. Their Chemical and Physical Characteristics and Their Determination in Thin Sections. By Joseph P. Iddings. 2nd edition, revised and enlarged. New York: John Wiley & Sons, 1911, 6 by 9 in., 617 pages, including index; two folding plates (one colored) and many small illustrations in the text; also 15 pages of tables. Cloth bound. Price, $5.00.

The book is divided into Part I, General Principles and Methods of Research, and Part II, Description of the Rock Minerals.

Chapter I relates to Chemical Principles and Characters and is a capital review of chemistry, reagents, tests, etc., covering 36 pages.

Chapter II treats of Physical Principles and Characters in Part, and is a proper and desirable following of the preceding chapter. This covers the items of hardness, gravity, optical characteristics, and the like. It also takes up the molecular structure of crystals and gives a comprehensive essay on Crystallography. This occupies about 60 pages.

Chapter III relates to Optical Properties (99 pages) and is full of interest, with detailed review of optical principles. It is worthy of careful study if one has been well grounded in optics. It gives one of the finest discussions of this rather difficult subject, with many illustrations from drawings and diagrams.

Part II gives descriptions of the rock minerals and consists of nearly 400 pages. The characteristics of the minerals described are in the order of Chemical Composition, Alteration, Crystallographic Characters, Optical Properties, Modes of Occurrence, Resemblances to Other Minerals, and Laboratory Production. The mineral list is very full and complete, with many illustrations of their respective crystalline forms.

Concerning this work in its earlier form one mining engineer of high standing says: "The book is complete and up to date, including such recent work as the studies of artificial feldspar and calcium silicates. It is a text-book of the highest class—perhaps too much so for beginners who have not the best teachers—yet is a book of much usefulness. To those who are interested in geology, and more especially mineralogy and petrology, this work of Mr. Iddings is of great value.

LIBRARY NOTES.

The Library Committee desire to return their thanks for donations to the Library. Since the last publication of the list of such gifts, the following publications have been received:

MISCELLANEOUS GIFTS.

C. L. Strobel, M. W. S. E.:
Reports of National Monetary Commission. Paper.

Chicago South Park Commission:
Report of South Parks, 1909, 1910. Pams.

P. Blakiston's Sons Co.:
Electro-Analysis, Edgar F. Smith. Leather.

McGraw-Hill Book Co.
Framed Structures and Girders, Vol. 1, Part 1. Edgar Marburg. Cloth.
Design of Walls, Bins, and Grain Elevators. Ketchum. Cloth (2nd edition).

Wm. Carroll, M. W. S. E.:
Annual Reports, Department of Electricity, Chicago, 1903-10. 8 vols.; cloth.

International Association of Road Congresses:
Bulletin, July, 1911. Pam.

Chicago Department of Public Works:
Rules and Regulations of Water Department. Pam.
Chicago City Manual, 1908. Cloth.

Engineering News Publishing Co.:
Width and Arrangement of Streets. C. M. Robinson. Cloth.

John Wiley & Sons:
Strength of Materials. H. E. Murdock. Cloth.

Virgil G. Bogue, M. W. S. E.:
Plan of Seattle. Municipal Plans Commission. V. G. Bogue, Engr. Paper.

David Williams Co.:
The New Building Estimator. Wm. Arthur. Cloth.
Contractor and Builders' Handbook. Wm. Arthur. Cloth.

B. E. Grant, M. W. S. E.:
Chicago City Manual, 1910. Pam.

Chicago Municipal Court:
Fourth Annual Report, 1910. Pam.

GOVERNMENT PUBLICATIONS.

U. S. Department of Commerce and Labor:
Pilot Rules for Rivers. 2 pams.

U. S. Geological Survey:
  Production of Iron Ore, Pig Iron and Steel in 1910. Pam.
  Production of Asphalt and Related Bitumens in 1910. Pam.
  Silver, Copper, Lead in Central States in 1910. Pam.

U. S. Bureau of the Census:
  Population in Wisconsin in 1910. Pam.

U. S. Department of Agriculture:
  Tidal Marshes and Their Reclamation. Pam.
  Swamp and Overflowed Land in the U. S., Ownership and Reclamation. Pam.
  Report on Drainage of Agricultural Lands in the Kankakee River Valley, Indiana. Pam.
  Reclamation of Tide Lands. Pam.
  St. Francis Valley Drainage Project in Northeastern Arkansas. Pam.
  Napthalene in Road Tars. Pam.

U. S. Bureau of Mines:
  Miners' Circular No. 5, Electrical Accidents in Mines. Pam.
  Bulletin No. 13, Resumé of Producer Gas Investigations. Pam.
  Bulletin No. 19, Physical and Chemical Properties of Petroleum of the San Joaquin Valley, Cal. Pam.

EXCHANGES.

Bureau of Railway Economics:
  The Cost of Transportation on the Erie Canal and by Rail. Pam.

New York Metropolitan Sewerage Commission:
  Preliminary Report on the Disposal of New York's Sewage. Pam.

New Orleans Sewerage and Water Board:
  Twenty-second Semi-Annual Report, 1910. Cloth.

Institution of Mechanical Engineers, London:
  Proceedings, January-February, 1911. Pam.

American Railway Engineering Association:
  Bulletins, 138-40. Pams.

New York City Board of Water Supply:
  Fifth Annual Report, 1910. Cloth.

Northeast Coast Institution of Engineers and Shipbuilders:
  Transactions, Vol. 27, 1910-11. Cloth.

Western Australia Geological Survey:
  Bulletin No. 41. Pam.

Canada Department of Mines:
  Bulletins, 1911. 3 pams.

Virginia Geological Survey:
  Biennial Report of the Mineral Production of Virginia, 1909-10. Pam.

Engineers' Society of Western Pennsylvania:
  Charter, By-Laws, List of Members, 1911. Pam.

Chicago Bureau of Public Efficiency:
  Repairing Asphalt Pavement. Pam.

Georgia Geological Survey:
  Preliminary Report on Drainage Reclamation in Georgia. Pam.

Institution of Electrical Engineers, London:
  Journal, September, 1911. Pam. List of Members, 1911. Pam.

Institution of Naval Architects, London:
  Transactions, 1911. Cloth.

Ontario Bureau of Mines:
  Twentieth Annual Report, 1911. Cloth.

Journal of the
Western Society of Engineers

VOL. XVI DECEMBER, 1911 No. 10

THE NEW PASSENGER TERMINAL OF THE CHICAGO AND NORTH WESTERN RAILWAY.

GENERAL FEATURES.

W. C. Armstrong, M. W. S. E.

Presented Sept. 6, 1911.

The question of adequate passenger facilities in the City of Chicago has been a problem of considerable importance to the Chicago and North Western Railway Company for a number of years. The enormous growth of suburban traffic in the last decade and the constant increase in the volume of through passenger traffic from year to year extending over a longer period, had so overtaxed the terminal facilities that some substantial increase in these facilities became an absolute necessity.

The old Wells Street Terminal had been developed to its utmost capacity. Further expansion was out of the question. It was hemmed in by the Chicago River on the south and west, Kinzie street on the north and Wells street on the east. Besides, the throat of the terminal yard crossed the north branch of the Chicago river, over which a movable bridge had to be maintained on account of navigation. It therefore became necessary to look elsewhere for a less restricted site.

The problem had been under consideration for several years before any active steps were taken in the matter. As the project involved the collection of a vast amount of data, extensive studies of all the possible schemes, and preliminary work of various character, it was thought that this work would be less hampered by premature publicity and could be carried on more expeditiously under a staff of engineers separate and distinct from the Railway Company's organization, but working under the general direction of the executive officers.

This preliminary work was placed in charge of Mr. John F. Wallace, M. W. S. E., by whom surveys and the collection of data were begun in the latter part of the year 1905. The work continued through the greater part of the year 1906.

The general scheme developed from these studies provided for a station building and terminal yard occupying the three blocks bounded by Lake street on the north, Canal street on the east, Madison street on the south, and Clinton street on the west. The station building was to front on Madison street and the entrance to the terminal yard was to be directly from the north, where the approach tracks would cross the P. C. C. & St. L. Ry. Co.'s tracks in Carroll avenue and several important streets. An overhead crossing of these tracks and streets was necessary; therefore, only an elevated terminal yard was possible.

A general map of the terminal territory is presented in Plate I. Prior to the construction of the new terminal approaches, the tracks of the Galena Division, approaching the city from the west, were elevated west of Ashland avenue, and descended to the surface at Ada street, from which point they continued as surface tracks into the Wells Street Terminal. They were crossed by overhead street viaducts at Sangamon street, Halsted street, Des Plaines street and Milwaukee avenue. The tracks of the Wisconsin Division approaching the city from the north were elevated north of Sangamon street and descended to the surface at Chicago avenue, from which point they continued into the Wells Street Terminal as surface tracks. They were crossed by overhead street viaducts at Halsted street, Chicago avenue, Erie street and Grand avenue.

The location of the Milwaukee avenue viaduct over the Galena Division tracks and the Grand avenue viaduct over the Wisconsin Division tracks did not allow sufficient distance in which to reach the elevation necessary for an overhead crossing of the P. C. C. & St. L. Ry. tracks on practical grades starting from the surface tracks at these points. It was therefore necessary to build new approaches to the terminal for each of these divisions. It was accordingly decided to divert the Galena Division tracks to the northward from a point near Bixby Court and locate the new approach parallel to the surface tracks and far enough north to pass the ends of the viaduct approaches, and to divert the Wisconsin Division tracks to the westward from a point near May street and locate the new approach approximately parallel to the surface tracks and far enough to pass the ends of the viaduct approaches on this division. The two new approaches unite at Jefferson street, from which point they pass around a curve to the southward, crossing over the Galena Division surface tracks, the P. C. C. & St. L. Ry. tracks and enter the terminal yard as above mentioned.

The Galena Division tracks from Bixby Court to Jefferson street are called the West Approach; the Wisconsin Division tracks from May street to Jefferson street are called the North Approach; the tracks forming the union of these two approaches from Jefferson street to Lake street are called the Terminal Section; while the tracks south of Lake street are called the Station Yard. These terms will be used in this article for distinguishing the different sections.

The general plan as outlined above was decided upon in the latter part of the year 1906 and arrangements were started for carrying out the construction work. A construction force for the work of preparing all maps, general and detail plans, and carrying on both the office and field work of construction, was organized under the writer, reporting directly to the Chief Engineer. General designs for the station building were started at the same time by the Company's architects, Frost & Granger, of Chicago, Illinois.

AUTHORITY.

An ordinance granting the Chicago and North Western Railway Company the right to construct and maintain a Passenger Terminal and the necessary approach tracks in accordance with the general plan outlined, was passed by the City Council of the City of Chicago on December 17, 1906. The ordinance provided for viaducts over all streets and alleys, and gave permission for the location of columns supporting girders in the center of all streets and immediately inside the curb lines of same. The minimum clear headroom above the surface of the street was fixed at 14 ft., with the following exceptions: Phillips street, 13 ft.; Austin avenue, 15 ft.; Jefferson street, 16.5 ft.; Kinzie and Clinton streets, 17 ft.; Carroll avenue, 17.5 ft.; Kinzie street, west of Ada street, 12.7 ft.; Noble street, 13.7 ft.; Lake st., 13.5 ft.; Randolph street, 13.5 ft.; Washington street, 15 ft. The minimum clear headroom for all alleys was fixed at 12 ft.

Washington street, being under the jurisdiction of the Chicago West Park Commissioners, was widened from 80 ft. to 120 ft. by an ordinance passed by this Board of Commissioners on February 14, 1907. Four lines of columns were provided for in this street; two immediately inside of the curb lines and two in the walls of the approach to the tunnel under the Chicago River at this point. This divided the street into two roadways, one being on either side of the tunnel approach.

Another ordinance was passed by the City Council of the City of Chicago on December 14, 1908, vacating certain alleys around which the Railway Company had purchased all the property and which would be no longer needed for public purposes. This materially reduced the number of alley viaducts to be constructed.

SURVEYS AND MAPS.

The first thing of importance in an undertaking of this character is a correct survey and correct maps of the territory covered by the work. The property surveys involved in this work were made by the Greeley-Howard Company of Chicago. Lines were run in the streets or on the sidewalks and the corners of each block were defined by crosses cut in sidewalks, 5 ft. either way from the street lines. The blocks were then sub-divided, the actual dimensions of each lot being fixed in proportion to its recorded dimensions, as in most all cases, blocks were found to either overrun or fall short of their recorded dimensions.

The surveys made by the Greeley-Howard Company were checked by the Engineering Department of the Railway Company, the various street and block lines being tied together in some form of closed figure and the accuracy of the work proven by traversing.

The latitudes and departures or co-ordinates were referred to a system of co-ordinate axes, so located that the entire territory involved would lie in the first quadrant. The axis of "X", running east and west, was located in Madison street, and the axis of "Y", running north and south, was located in the vicinity of Ashland avenue. The equation of each block line or other line, the location of which was desired, was then established with reference to these co-ordinate axes. Co-ordinates of any point on any line could then be determined, or the intersection of two lines could be fixed by equating their respective equations with each other and solving the resultant equation for the required co-ordinates.

After the map was completed, all track locations were projected upon it and fixed in position by establishing the equations of tangents and curves with reference to the same co-ordinate axes. Intersections of track lines with street lines were determined by the combination of their respective equations. The location of all lines of columns for the support of structures and the individual columns in these lines were also fixed in the same manner. It was necessary that the field work of these surveys be made with extreme accuracy and all calculations of same carefully checked, for the location of all structures was dependent upon the accuracy of the field work and calculations. It was impossible to make direct measurements for tracks and structure. No center lines of tracks could be run, for the reason that buildings which had not been removed obstructed the lines of sight. Locations for structures had to be established from indirect measurements and calculations therefrom. This was true of practically all structures upon the approaches, and it was not until many of them were built that the buildings were all removed and the accuracy of the calculations could be verified by running center lines.

PREPARATORY WORK.

A large amount of preparatory work was necessary before any actual construction could be started. The terminal territory was all improved city property and covered with buildings of various types. The blocks upon which the main building and station yard were located was a business district and covered principally by brick structures from one to six stories in height. The North Approach and a considerable part of the West Approach were covered with factory buildings, while the extreme north end of the North Approach and the remainder of the West Approach were covered principally by tenement houses and an inferior class of residences. The buildings were sold to wrecking contractors, who wrecked them, retained the salvage and cleaned up the debris, or moved them bodily to other sites. In all there were 455 buildings wrecked or removed, 66 of which were four stories or more in height.

Raising the Chicago and Oak Park Elevated Railroad.

The Terminal tracks at the entrance to the station yard cross Lake street which was occupied by the tracks and structure of the Chicago and Oak Park Elevated Railroad. This structure consisted of columns placed just outside of the curb lines, connected by cross girders spanning the street. To these cross girders were attached plate girder stringers 5 ft. deep, which carried the track ties. The span length of these stringers varied from 40 ft. to 58 ft. There were four lines of stringers carrying two tracks, although provisions were made in the cross girders for adding two additional lines of stringers on either side of the present stringers for two future tracks.

The elevation of the established grade of Lake street at this point was +14.00 referred to city datum. The elevation of the bottom of the stringers of the elevated road was +39.63, and the top of rail +45.55. The Ordinance required a minimum clear headroom of the C. & N. W. Ry. structure over the street of 13.5 ft. The depth of the track floor would be 4.0 ft., and it was desired to have at least 17 ft. clear headroom over the top of the C. & N. W Ry. rails. It was therefore necessary to raise the elevated railroad tracks, and also to remove the girders and columns supporting these tracks on that part of Lake street to be occupied by the C. & N. W. Ry. tracks.

An agreement was concluded between the two companies which provided, in effect, as follows:

1. A four-track three-truss span 155 ft. long would be substituted for that part of the C. & O. P. R. R. structure over the C. & N. W. Ry. tracks. 2. The top of the C. & O. P. R. R. rail should be raised to elevation +50.64 over this span and the depth of floor should not exceed two feet. 3. The C. & O. P. R. R. structure should be raised to meet this elevation by easy grades in each direction—the approach from the west to extend from the west line of Union street, a distance of 1,295 ft., and the approach

from the east to extend from the west end of the swing bridge over the Chicago river, a distance of 647 feet. 4. The C. & N. W. Ry. company would prepare all plans, furnish all material and perform all work necessary in making these alterations at its own expense, all of which were to be subject to the approval of the C. & O. P. R. R. Co.

In the execution of this work the entire structure was first raised to the fixed elevation. Extensions were riveted on the bottoms of the columns and new foundations were built under same. The raising of the structure was effected with a large number of ordinary jacks. "A" frames of 12 by 12 in. timbers were placed under each end of each cross girder. These A frames were bolted rigidly to the columns. The sills of the frames were made long enough to span the foundation pit and secure plenty of bearing room outside of the sheeting for blocking and working the jacks. A sketch of these details is shown in Fig. 1.

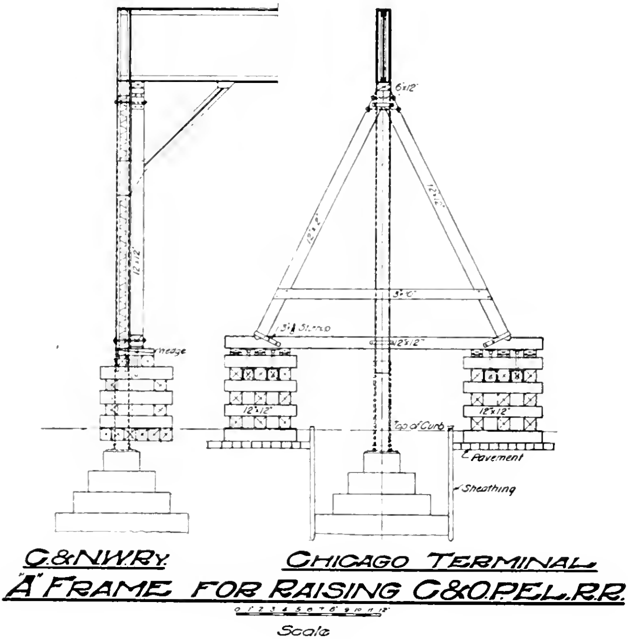


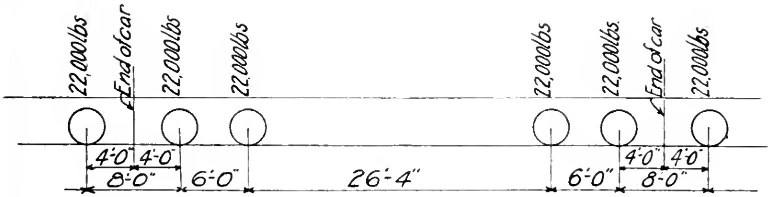
FIG. 1.

As traffic was not to be interrupted on the C. & O. P. R. R. tracks during the progress of the work it was necessary that the raising be carried on by easy stages. No girder was allowed to be raised more than one inch above the adjoining girders at any time. Heavy oak wedges were placed between the sills of the A frames and the blocking supports, which were driven tight as fast as the sills were raised by the jacks, so that the weight of moving trains was never carried on the jacks. The work was completed without any mishaps and without delay to any trains.

The 155 ft. truss span over the C. & N. W. Ry. tracks is a riveted structure throughout, with six subdivided panels. It has stiff bottom chords to which the 15 in. I-beam floor beams are riveted. The entire structure is carried on four heavy columns at the four respective corners of the span. It was found impracticable to place direct supports under the center truss, principally on account of the Illinois Tunnel Co's. tunnel located in the center of the street, the top of which was 41 feet below the surface of the street. This truss was therefore carried on a heavy box girder, 10 feet deep, supported by columns located just inside of the curb line; which columns also carry the outside trusses direct. Plate II shows a general plan and details of the more important features of this structure.

It will be seen that the trusses are very heavy. This is due to the rather drastic specifications imposed by the C. & O. P. Ry. Co., which were as follows:

Loading.—Train of Motor cars with following wheel base and axle loads:



Impact.—20% of Live Load.

For four tracks fully loaded 87½% of full Live Load to be used.

Tension.—11,000 lbs. per sq. in.

Compression.—$$P = \frac{11{,}000}{1 + \dfrac{L^2}{36000r^2}}$$

Bearing—	Shop rivets	15000	lbs.	per	sq.	in.
	Field rivets	12000	"	"	"	"
Shear—	Shop rivets	7500	"	"	"	"
	Field rivets	6000	"	"	"	"
	Web plates	9000	"	"	"	"

There is one unusual feature in the truss design that may be of interest. That is the excessive camber given the span. The two ends of the span are level, while the approach grade from the east is 0.5%, and that from the west 0.427%. It was found that if these grades were joined by a vertical curve of the same length as the span, the versed sine of this curve would be about 2 inches. The trusses were therefore calculated for 2¾ in. camber, ¾ in. being the calculated dead load deflection. The adoption of this excessive camber accomplished at the same time the rounding off of the grades and the drainage of the floor to the ends of the span.

No provision was made in the shop work for this curvature in the stiff bottom chords. The joints were built square and the camber forced into the chords by deflection during erection. There was some question as to what initial strain this deflection would produce in the chords. The problem did not admit of exact calculation, as the moment of inertia of the chords was not uniform and there was a certain amount of play in the rivet holes which could not be evaluated. The maximum amount of this initial strain was, however, approximated by taking a panel length of the heaviest section of the bottom chord of the center truss, and assuming it supported at the ends and loaded at the center with a load that would produce a deflection equal to the versed sine of a panel-length arc of the vertical curve. This gave a tension of 2,700 lbs. per sq. in. in the extreme fibers at the top of the chord, and, of course, a corresponding compression on the bottom fibres. As soon as the falsework was removed and the span carried its own weight ¾ in. of this camber would disappear in dead load deflection, and a certain part of the initial strain would also disappear. If load enough were added to deflect the chords to a straight line the initial strain would all disappear. These conditions considered, together with the liberal unit stresses used, it seemed to be perfectly justifiable to disregard the initial strains.

Another interesting feature of this span is the floor construction. It was required that the depth of floor from top of rail to the clearance line underneath should not exceed 24 in. While it was not required that the floor be absolutely water tight, it was required that the construction be such as to prevent debris of any kind falling through on the tracks below and also to prevent smoke from locomotives underneath penetrating the floor. It was also desired to have all steel work protected from locomotive gases by a complete envelope of concrete. 15 in. I-beams were used as floor beams. 12 in. channels with flanges turned up were riveted to the top of the I-beams forming troughs in which the rails were laid and fastened. In order to make a group of floor beams act as a unit under the concentrated wheel loads, lines of diaphragms were introduced under each rail. These diaphragms were made of short sections of 12 in. I-beams attached to the webs of the floor beams by connection angles. The bottom flanges of the 12 in. I-beams were coped and placed flush with the bottom flanges of the floor beams. A continuous 5 in. by $\frac{3}{8}$ in. plate was then riveted to the bottom of the 12 in. I-beam diaphragms. This formed a sort of longitudinal girder under each rail. There was no continuous steel top flange to this longitudinal girder, unless the 12 in. channel above referred to be regarded as a top flange; but, it was assumed that the concrete with which the floor was filled together with this channel would take care of all compressive strains.

In order to reduce as much as possible the dead weight of the floor, and at the same time preserve the element of protection to the steel by the concrete envelope, the concrete was made cellular. This was effected by placing wooden boxes in the spaces between the floor beams. The boxes were kept free from the steel work so that the concrete would envelop the latter completely. The lower flanges of the beams were wrapped with expanded metal and a sheet of expanded metal extended from one beam to another, resting on the lower flanges of each. The concrete was made of torpedo sand and cement mixed very thin so that it would pour readily. As the wooden boxes were entirely surrounded with concrete they could not be removed; and as it was necessary to provide for the escape of any water that might collect in the cells thus formed, holes were bored in the bottoms of the boxes which communicated with holes extending through the concrete below. The holes in the concrete

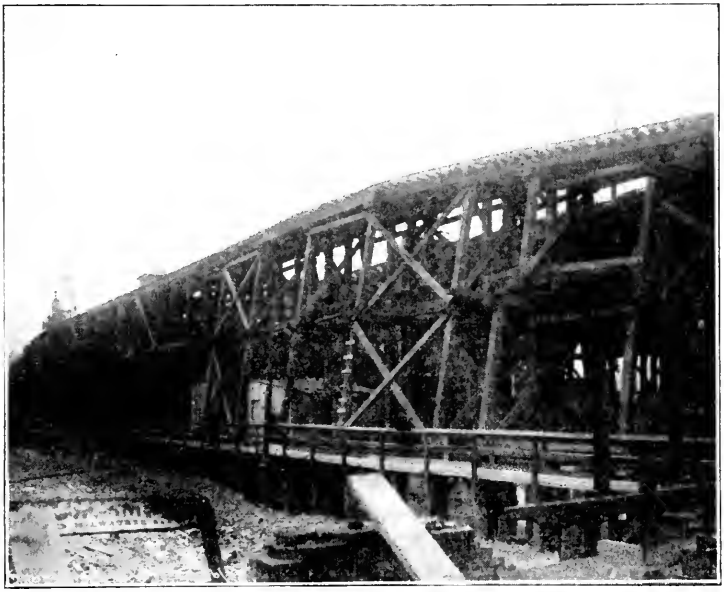


Fig. 2.—Falsework for Erecting C. & O. P. R. R. Bridge, 155 ft. Span.

were made by placing blocks on the boards forming the lower surface of the concrete, which were withdrawn when the forms were removed. These blocks were 4 in. sq. at the base and in the form of a truncated pyramid to facilitate their withdrawal. Two hundred and fifty tons of dead weight were saved by this construction.

The structure carrying the C. & N. W. Ry. tracks is the standard trough floor construction which has been used to a considerable extent for track elevation work. The lines of girders inside of the curbs are connected to the large columns carrying the 155 ft. span. There is a similar line of girders with column supports in the center of the street.

The columns at the corners of the 155 ft. span are supported on four concrete caissons, ten feet in diameter, and founded on hard pan at elevation —70, or 84 feet below the street level. The caissons are "belled" out to 16 ft. in diameter at the bottom. The pressure on the hard pan from dead load only, is 3.7 tons per sq. ft.; with full live loads included the pressure amounts to 4.7 tons per sq. ft. The caissons were sunk by the open method and no difficulty was experienced in the work.

The erection of the span, on account of maintaining traffic on the C. & O. P. R. R. tracks was a difficult problem, and involved some interesting features. The elevated tracks were spread apart to 77 ft., center to center, the center of each track being placd 12 ft. outside the center of the outside truss. These tracks were carried on temporary timber trestles which were also planned to serve as falsework to support the outside trusses. The center truss was carried on timber bents built up from the center of the street. In Fig. 2 is shown a general view of the timber trestle and a detail view is shown in Fig. 3. A view of the completed span is given in Fig. 4.

The work of raising the C. & O. P. R. R. elevated structure and erecting the 155 ft. span including all foundations was carried out under contract by Geo. W. Jackson, Inc. This contract included the furnishing of all material used for the extension of columns and new knee braces between columns and girders. The structural steel work for the 155 ft. span and its supports was furnished by the Pennsylvania Steel Company, but was erected by George W. Jackson, Inc.

Sewers, Water Pipes, Electric Wires, Etc.

Other work preparatory to construction, consisted in changing all street car tracks in subways to give proper clearance for columns located in the centers of streets, the changing of sewers, water pipes, gas pipes and electric conduits, where their location interfered with the construction work and the removal of all overhead telegraph, telephone and electric light wires.

The work in all cases was done by the forces of the corpora-

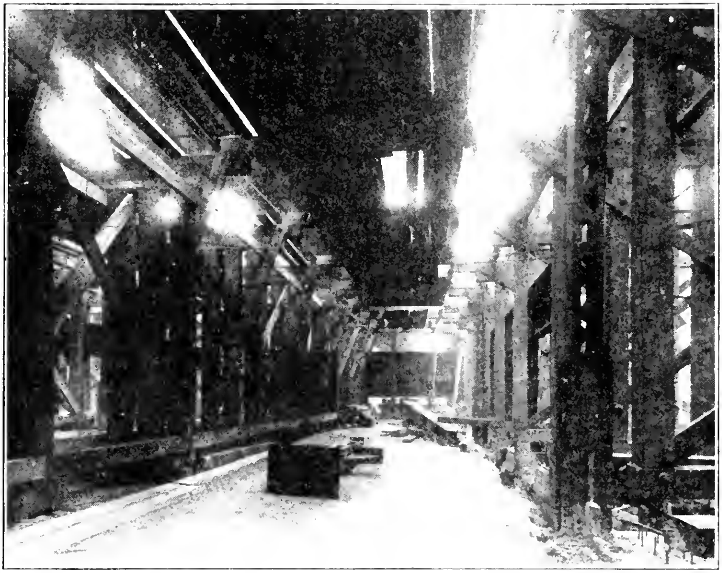


Fig. 3.—Falsework for Erection of 155 ft. Span C. & O. P. R. R.

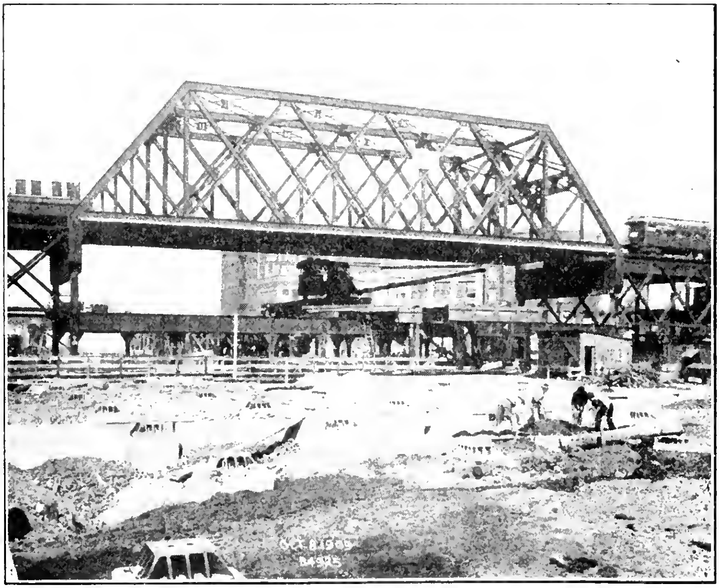


Fig. 4.—General View, 155 ft. Span, C. & O. P. R. R. at Lake St.

tions to which these properties belonged except the changes in sewers, which were made under contract between the railway company and sewer contractors. Street car tracks were simply spread apart in the subway and brought back to their original alignment on either side; water and gas pipes were relocated in the roadways clear of the foundations for center and curb line columns; sewers were diverted in the same manner, with additional manholes built at points of deflection; all overhead wires were rearranged, and wherever practicable were placed in underground conduits, so that no wires were left crossing over the terminal tracks.

PLANS.

While the preparatory work above referred to was in progress, extensive studies were being made of the station building, power house, track arrangement, train shed, viaduct structures, retaining walls, etc., and detail plans of same were worked up. Each of these will be taken up in proper order and more fully discussed.

STATION BUILDING.

The main station building is a four-story granite structure of the early Italian Renaissance style of architecture. It has a frontage of 320 ft. on Madison street and a depth north and south of 218 ft. The exterior walls on Canal and Clinton streets are continuous with the enclosing walls of the station yard and train shed, which rise to a height of 48 ft. above the street.

A view of the structure, showing the Madison street front and the Canal street side is given in Fig. 5, and a plan of the street level floor is shown in Plate III. As this plan also shows the subdivision of the space under the track floor of the station yard for the various facilities in connection with the station operation, the general description to follow will apply to the entire street level area between Madison street and Lake street.

The main entrance to the station building is on Madison street. Here is a lofty Doric portico supported on a colonnade of six granite columns, each seven feet in diameter at the base and 61 ft. high. Immediately back of this colonnade entered by three great arches, is a vaulted vestibule, 132 ft. wide, 22 ft. deep and 40 ft. high. At each end of this vestibule are broad granite stairways to the main waiting room on the track level floor. There are also entrances from Canal and Clinton streets through vestibules of simpler architectural treatment. These vestibules lead directly into a large public space of 22,000 sq. ft. There are no seats in this area. It is simply a space for the circulation of passengers in transacting the necessary business preparatory to taking their trains, or upon their arrival from trains.

Arranged around this public space are the ticket offices, information bureau, parcel check room, lost and found department, bag-

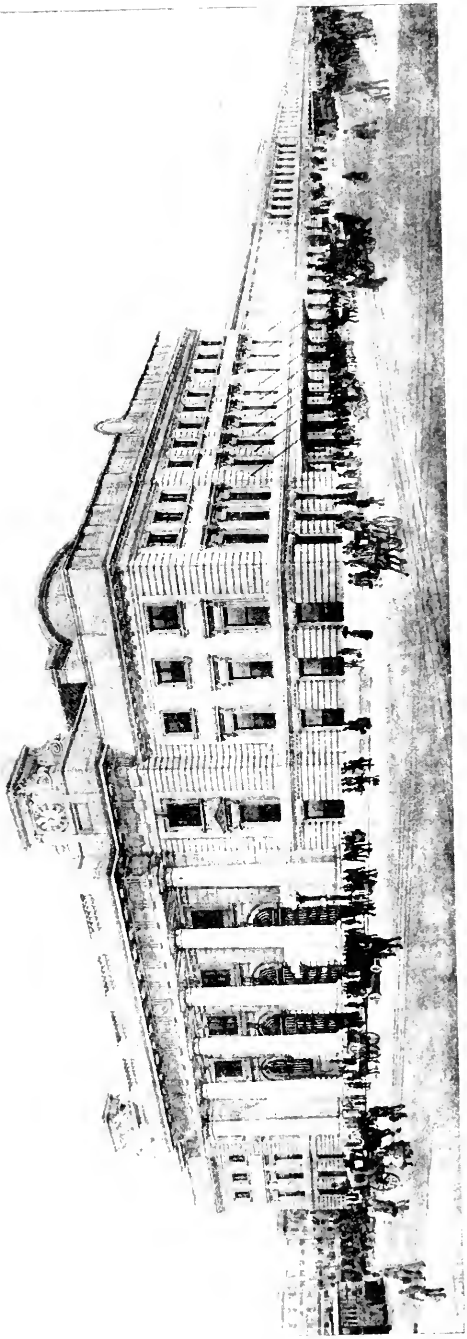


Fig. 5.—View of the Terminal, Madison and Canal Street Fronts.

gage check room, telegraph offices, telephone booths, drug store and lunch room. Here the traveler will secure his tickets, check his baggage, file his telegrams, 'phone his friends, purchase his literature and pills, eat his lunch or wait a more sumptuous repast in the hall above, after which he ascends to the main waiting room on the second floor, where the "best of everything" is provided for his comfort and convenience.

The baggage check room communicates directly with the in-baggage room. The out-baggage room is located north of Randolph street. Communication between the baggage check room and the out-baggage room is effected by pneumatic tube. Below the in-baggage room is a basement for baggage storage. Seven hydraulic elevators pass from this basement through the in-baggage room and up to the track floor. Immediately north of the in-baggage room is a driveway 50 ft. wide, with entrance from Clinton street for baggage wagons. Kinnear rolling doors open directly from the in-baggage room to this driveway.

Directly east of the in-baggage room and driveway is a large carriage concourse with entrances from Canal street and Washington street and in direct communication with the public space in the station building. There is also a small carriage concourse on Clinton street which communicates with this public space through the Clinton street vestibule. This carriage concourse is intended for the more private uses—special parties, funerals, etc. A private lobby and an elevator leading to the track floor is provided in direct connection with it.

Next north of the baggage driveway is Washington street, 120 ft. wide. The sidewalks are each 19 ft. wide, and two roadways each 28 ft. wide. Between these roadways and separated from them by a concrete balustrade enclosing the columns supporting the track is the open approach to the tunnel under the Chicago River. A more complete description of this tunnel approach will be given later.

Immediately north of Washington street are the facilities for handling and distributing in-coming mail and the U. S. Post Office sub-station. Mail wagons enter a driveway here from Clinton street. Along this driveway is a trucking platform upon which are placed four large distributing tables. The mail sacks from in-coming trains are delivered through chutes upon these tables, from which they are trucked to the mail delivery wagons or into the Post Office sub-station. The sub-station is equipped with all modern conveniences and furnished complete by the railway company. A pneumatic tube service has been installed by the Chicago Postal Pneumatic Tube Company to connect with the Post Office and other postal sub-stations in the city. A mail street car track enters the mail wagon drive from Clinton street for the receipt and delivery of such mail as is handled in that way.

Next north of the Post Office sub-station is the suburban concourse. This is a passageway 50 ft. wide extending through the station from Canal street to Clinton street. Stairways lead from each platform on the track floor to this concourse, providing a quick exit from all trains. This is for the benefit of commuters who may find it more convenient than passing through the main building.

The emigrants' waiting room is located just north of the suburban concourse and communicates with it. Emigrants arriving on trains in the station may be brought down the stairways, through the concourse and into their waiting room, and those departing can reach their trains in the same way, without going through the main building.

An entrance to this waiting room is provided from Clinton street for the use of those arriving by transfer from other stations in the city. Adequate facilities are provided for the care and comfort of emigrants. A kitchen and lunch room serves them with food. Besides there are toilet rooms, bath rooms for women, and a laundry room equipped with a laundry dryer.

The central portion of the space between the suburban concourse and Randolph street has not been assigned for any particular use. This space has not been finished off inside and will be reserved for future use.

Between this unassigned space and Canal street is a large cab and automobile stand. Entrance for vehicles is made from Canal street, while passengers leaving the train platforms by way of the suburban concourse may readily secure a conveyance at this point.

Immediately north of Randolph street is a trucking space 25 ft. wide and extending the full width of the station. This trucking space communicates directly with each platform on the track floor by means of eight electric elevators, and also communicates directly with the express room, conductor's train box room, out-baggage room and out-mail room. At the extreme east end of the trucking space is a room for handling and dispatching railway mail.

The method of handling baggage, express and mail is by truck from the respective rooms into the trucking space and up the proper elevator to the track floor. It is only intended, however, that the express to be handled in this way will be that handled on suburban trains and "late arrival" packages, as all express cars continue to be loaded on the express car tracks in the Wells street terminal, and those cars which are to be attached to regular passenger trains are switched around by way of the North Approach on to the out-going train in the new station where the late arrival packages will be loaded before departure.

Likewise, the mail which will be taken from the mail room through the trucking space and up these elevators will be the late arrival pouches. A special mail elevator is provided in the mail room which ascends to a mail platform on the track floor where tracks are provided upon which to stand cars for loading at all times. The mail cars are removed from these tracks only a few minutes before the departure of trains to which they are to be attached and all mail received after the removal of the car will be taken through the trucking space and up the proper elevator to the train.

The express, baggage and mail rooms open to the driveway on the north through Kinnear rolling doors. This driveway extends the full width of the station with entrances at both Canal and Clinton streets.

North of the driveway on the Canal street side is the Registered Mail Post Office, with commodious wagon space, a room for the receiving and dispatching clerks, and an elevator leading to the mail platform above. This elevator can also be used for the regular mail in case of a congestion in the mail elevator south of the driveway.

Second or Track Level Floor.

The track level floor is shown in Plate IV. The main waiting room is located on this floor. It is reached by a grand stairway in the center of the building leading from the public space on the street floor, and also by two winding granite stairs at either end of the vestibule at the Madison street entrance. This room is the principal architectural feature of the station. It is 100 by 200 ft. in extent and has a vaulted ceiling 85 ft. high. The walls are of pink Tennessee marble, columns of green mottled scagliola and the ceiling vault of guastavino tile with richly ornamented terra cotta ribs.

Arranged conveniently around the main waiting room are the woman's room, dining room, barber shop, smoking room, toilet rooms, news stand and telephone booths. The main waiting room opens directly to the concourse through a series of double doors.

The concourse is 60 ft. by 320 ft. and is entirely enclosed and heated. Separating it from the station yard and passenger platforms is a glass partition set in steel framework, with a series of glass paneled steel sliding doors. Direct entrance to the concourse is provided by a grand stairway from Canal street and another stair from the Clinton street vestibule.

Third Floor.

On the third floor utilization is made of the space around the upper part of the main waiting room and concourse. A plan of the third and fourth floors is shown in Plate V. Occupying the east wing and a greater part of the south front are arranged the offices for the Galena and Wisconsin Divisions, and the Terminal Superintendent. In the west wing are several rooms devoted exclusively to the comforts and needs of women patrons. They include a retiring room, commodious toilet and bath rooms, tea room and emergency rooms. The rooms last named are equipped with couches and beds for the care of women travelers who may be taken ill. This entire group of rooms is under the care of a matron whose office is located centrally with respect to the group.

At the north end of the west wing is the men's writing room and a barber shop with a connecting toilet and bath room. These are intended to supply dressing room facilities and such accommodations as one might need who wishes to spend only a few hours in the city, and who does not wish to go to a hotel. They may be reached by a stairway from the west end of the concourse or by elevator from the street floor or concourse.

Fourth Floor.

The east wing of the fourth floor is utilized for conductors' and collectors' reading rooms and locker rooms, and the Electrical Engineer's offices and laboratory. A portion of the south front is occupied by the Pullman Co.'s offices. The balance of the south front and the entire west wing is reserved for future assignment.

Basement.

In the basement of the building are located the kitchen, storerooms, refrigerator room, butcher shop, rest rooms and toilets for women employees, lounging and locker rooms for brakemen, baggagemen and station employees, baggage storage room, a large public toilet and a large central space in the western portion of which the elevator machinery is located. A small auxiliary power and heating plant is located in the northwest corner. A plan of the basement is shown in Plate VI.

Elevator Service.

There are 23 elevators in the terminal station. They are all indicated by number on the various floor plans. Nos. 1 to 13 inclusive are hydraulic elevators. The locations and services performed by these elevators are as follows:

Nos. 1 and 2 in main station building near Canal street entrance extend from basement to fourth floor. They are principally for serving offices on third and fourth floors, but may also be used by the public between the street floor and main waiting room.

No. 3, in main station building near southwest corner, extends from basement to fourth floor. The principal use of this elevator is for women in reaching the woman's waiting room on second floor and the woman's rest rooms, tea room, etc., on third floor. It may also be used by the public in reaching the main dining room on the second floor, and will also be used in the future in reaching any facilities which may be located in the present unfinished portion of the fourth floor.

No. 4, in main station building near Clinton street vestibule, extends from street floor to fourth floor. It opens into a lobby off the public space on the street floor, and communicates directly with the concourse on the track floor. It will be principally used by invalid or crippled passengers between the street floor and the concourse. It is also the most direct means of reaching the barber shop and dressing rooms on the third floor.

No. 5, in main station building, near carriage entrance on Clinton street, extends only from basement to street floor. This elevator is only for the use of station employees.

No. 6, in train shed near carriage entrance on Clinton street, extends only from street floor to track floor. It is for the use of private parties, funerals, etc.

Nos. 7 to 13 inclusive, in train shed at ends of tracks, extend from baggage basement to track floor only. These are baggage elevators exclusively.

No. 14 to No. 23 inclusive are electric elevators.

Nos. 14 to 21 inclusive, in trucking space north of Randolph street, extend from street floor to track floor. These are for baggage, express and mail.

No. 22, in out-mail room, extends from street floor to track floor, and is for U. S. mail only.

No. 23, in Registered Mail Department, extends from street floor to track floor. It is for registered mail principally, but may be used for all out-going U. S. mail.

The main station building with its foundations was erected by the Geo. A. Fuller Co. under contract which also included the train-shed roof and walls and the finishing of all rooms under the track floor.

Foundations Under Station Buildings.

In Plate VI is shown the location of the caissons supporting the station building and a general plan of all foundations under the station yard and power house. There are 172 caissons in all under the station building varying from four to eight ft. in diameter. The caissons under the external walls and all points of heavy concentrated loads extend to rock. The elevations of the rock foundations vary from —96.25 to —105.67. The general elevation of the rock surface may be regarded as about —100.00 or 114 feet below street level. The surface of the rock is quite irregular with a slight dip towards the east. Seventy-seven of the interior caissons extend into the hard pan at elevations varying from —63.69 to —74.08 and two are founded in hard clay at elevations of —49.25 and —56.25 respectively. The caissons founded in hard pan and clay are belled out at the bottom to diameters varying from seven to twelve ft. according to the pressure.

Some difficulty was met in sinking caissons to rock on account of a stratum of boulders and water bearing sand which overlaid the rock. A few of these caissons were carried down to the foundation by the open method; but the difficulties became so great, and the flow of water carried in such quantities of sand that it was feared

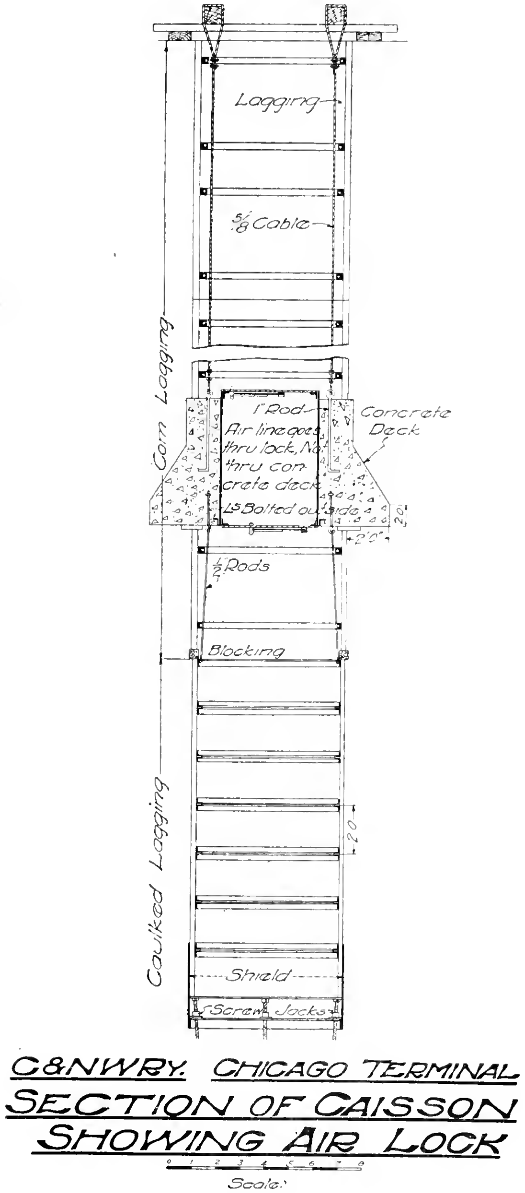

Lagging
5/8 Cable
Corr. Lagging
1" Rod
Air line goes thru lock, Not thru concrete deck
L's Bolted outside
Concrete Deck
2'0"
2'0"
1/2" Rods
Blocking
2'0"
Caulked Lagging
Shield
Screw Jacks
C&NW RY. CHICAGO TERMINAL
SECTION OF CAISSON
SHOWING AIR LOCK
0 1 2 3 4 5 6 7 8
Scale.

FIG. 6.

large pockets would be formed outside of the caissons which might result in dangerous settlements of the surrounding material. The use of air was therefore resorted to.

The air lock was placed in the hard pan stratum as far below the surface as possible. The shaft was enlarged at this point, and the lock was sealed in a collar of concrete. The lock was 4½ ft. in diameter and 5½ ft. long and was made collapsible so that it could be removed when the caisson was filled with concrete below. A sectional view of this construction is shown in Fig. 6.

A circular shield five ft. long and made of ⅜ in. steel plate was inserted below the lock. Around the cutting edge of the shield an angle was riveted as shown in the sketch. Sections of lagging, two ft. long, were introduced inside of the shield as the latter advanced. The lagging was composed of tongued and grooved plank to which were bolted circular angle bands at the top and bottom. The joints in the plank were caulked with oakum and tarred to make them as nearly water tight as possible. Each section was made up in parts small enough to be passed through the air lock and were assembled in place. The outside diameter of the sections of lagging was made to fit closely the inside diameter of the shield.

Between the bottom angle of the lagging and the angle around the cutting edge of the shield, jack screws were placed for forcing the shield downward. Whenever the shield was forced down far enough, and the material was excavated, the jacks were removed and another section of lagging was put in place. The top angle of the lower section of lagging was bolted to the bottom angle of the upper section after a rubber gasket had been inserted between them to prevent the escape of air.

With all the precautions taken to prevent the escape of air it was found that it did escape quite rapidly. Part of it escaped through the sections of lagging; some escaped through the joints between the lagging and the shield; and a great deal escaped through the gravel and boulder stratum through which the caisson was being sunk. Evidence of this was shown in the air bubbling up around caissons that had been already completed. This occurred in many instances at quite a distance from the caisson under pressure.

After considerable experimenting, it was found that the escape of air through the lagging and the shield could best be prevented by plastering with mud. For this purpose the soft blue clay found above the hard pan proved very efficient. The loss of air through the gravel and boulders could not be prevented and the only way to overcome the loss was by increasing the pressure and forcing in a greater supply of air. The air pressure maintained depended upon the loss of air, but did not exceed 22 lb. at any time. Eighty-eight caissons under the station building were finished by the pneumatic process. The pneumatic work was done by The Foundation Co. of New York.

Foundations in Station Yard.

The foundations supporting the track floor columns are concrete pedestals. In the train shed, where the columns are placed under the center of the tracks, each pair of columns is supported on pedestals with a common base; but north of the train shed, where the columns are spaced at regular intervals, each one is carried on an independent pedestal. The pedestals are generally 4 ft. square on top and built in three courses. The sides of each course are vertical and stepped, as that method required less expensive forms than making the sides battered and involved the use of no more material All pedestals are supported on piles from 40 to 45 ft. in length.

STATION YARD.

The station yard, shown in Plate IV extends from the north line of the concourse in the station building to the south line of Lake street. There are sixteen station tracks and eight passenger platforms. The tracks are arranged in pairs, 12 ft. and 12 ft. 6 in. between centers, except the two outside tracks next to the train shed walls. The tracks 12 ft. 6 in. between centers have belt conveyors installed in the track floor between them, upon which in-coming mail is thrown from the mail cars and transported to the mail distributing room. These conveyors will be described in more detail in a later paragraph.

The shortest track is 623 ft. long and will hold a train of eight common coaches or seven Pullman coaches including an engine. The longest track is 1,147 ft. and will hold a train of seventeen common coaches or fifteen Pullman coaches including an engine. The total standing capacity of the yard is about 200 cars of all kinds.

The tracks are level south of Randolph street, the elevation of the top of rail being +34.00, or about 20 ft. above the street level. Between Randolph street and Lake street there is a descending grade of 0.65%, rounded off with vertical curves and reaching a minimum elevation of +31.6 at the center of Lake street.

The platforms have a maximum width of 16 ft. 9 in., and are 8 in. above the top of the rail. They are all somewhat narrower at the extreme north end due to the convergence of the tracks. The longest platform extends from the concourse to Lake street, a distance of 1,045 ft. The aggregate length of all platforms is 7,160 ft.

In the northeast corner of the station yard are four standing tracks for mail cars. Elevators communicate between the mail rooms on the street floor and the platforms along these tracks.

The entire station yard and the throat of same as far north as the north line of Fulton street are carried on steel construction, except the small triangle between Milwaukee avenue and Fulton street, which is a sand filling between concrete retaining walls. All tracks outside of the train shed are of the ordinary cross tie construction on broken stone ballast.

Snow melters are placed at various points outside of the train shed for the rapid disposition of accumulations of snow. They consist of steel pans 3 ft. wide and 6 ft. long, with semi-circular bottoms, containing perforated steam coils. They are set down in the track floor, and have removable steel plate covers flush with the top of tie. They are provided with drain pipes which connect with the sewers, for carrying off the water.

TRAIN SHED.

No feature of the terminal was given more thorough and exhaustive study than that of the train shed. The high one-span arch was about the only kind not considered. While a number of feasible plans were worked out, none of them seemed better suited to the requirements than that known as the Bush type. This shed was first built for the Hoboken terminal of the Delaware, Lackawanna & Western Railway at Hoboken, New Jersey. It was designed and patented by Mr. Lincoln Bush, M. W. S. E., at that time Chief Engineer of the D. L. & W. Ry. Co. The distinctive feature of this shed is a continuous slot directly over the center of each track through which the locomotive exhausts. This is the feature that is covered by patent and may be applied to sheds of different structural design.

In a general way the structural features of the C. & N. W. Ry. shed are similar to those of the one at Hoboken, and consist of series of arched girders spanning each pair of tracks and supported on columns in the center of the platform. The question of placing the columns in the platform or between the tracks was very carefully considered, and plans were drawn up for each scheme. A very effective design was made with columns between the tracks; but it required that the tracks be spaced 15 ft. apart to obtain the same lateral clearance that was given with tracks 12 ft. apart when the columns were placed in the platforms, the columns being one foot wide. The width of platform was, of course, correspondingly narrowed. It can readily be seen, therefore, that columns between tracks is not economical, for there would be two feet more of lost space for every platform and pair of tracks, assuming that there is necessarily one foot of lost space due to the column wherever it is placed. It was therefore decided to place the columns in the platforms.

The train shed covers an area of 265,800 sq. ft., or a little over six acres. Over the seven easternmost tracks it extends a distance of 738 ft. north from the north line of the station building, while over the nine remaining tracks it extends 891 ft. from the station building. The notch at the north end is made necessary by the curvature of the tracks.

The steel work was designed to carry a snow load of 20 lb. per sq. ft. of horizontal projection in addition to the actual dead load of the structure. No wind load was considered. The following unit stresses were allowed in proportioning:

Tension, 15000 lbs. per sq. in.

Compression, $$P = \frac{15000}{1 + \frac{l^2}{13500r^2}}$$

Shear, 9000 lbs. per sq. in. on webs (gross section)
Rivets, shop 11000 lbs. per sq. in.
Field 8800 " " " "

Bearing, Rivets, shop 22000 lbs. per sq. in.
Field 17600 " " " "

A typical plan of the train shed, platforms and track floor construction is shown in Plate VII. The lower flange of the train shed girders is bent to a five-centered curve. The top flange follows a simple curve to within a few feet of the ends, from which point it is straight and tangent to the curve. The girders are spaced 25 ft. 6 in. apart and at right angles to the tracks, except at the street crossings, where the spacing and direction was made to correspond with the street lines. The end connection angles are riveted to the girder at one end and bolted at the other end, the play in the bolt holes being intended to provide for the small variations in length due to changes of temperature. The connection angles are bolted rigidly to the sides of the column. Connecting the girders together longitudinally are two latticed struts over each track which form the framework for the concrete walls of the smoke duct. One of these struts is shown in Section B-B.

The columns are connected together by a trough shaped strut formed of two 10 in. channels, with a plate riveted to the bottom and with curved brackets at the ends, shown in Section A-A. The curve of these brackets conforms very closely to the end curves of the bottom flange of the girders, and both terminate in a cast iron capital around the top of the column. The purlins are I-beams attached to the column struts and the smoke duct struts—the center purlins being curved to conform to the top flange of the girder. The skylight frames are Z-bars resting on bulb angle headers attached to the girders and purlins, as shown in the sections.

All storm water drains to the valley over the columns. The method of draining across the smoke duct walls is shown in Section C-C. Down spouts are provided in the center of every alternate column, and the gutters are graded to drain to these downspouts. The downspouts connect with horizontal runs of pipe beneath the track floor, to which are also connected the track floor drains, and lead to the sewers through outlet pipes down the track floor columns.

The smoke duct walls are of concrete, 5 in. thick and 36 in. apart except at the north end, where the tracks are on curves, they are slightly widened. The bottom of the duct walls is in all cases 15 ft. 4½ in. above the top of rail, or just high enough to clear by a few inches the highest points on the engines and cars. The depth of smoke ducts is generally 5 ft. 3 in. although north of Randolph street, where the tracks are on a descending grade, the top of the smoke duct is kept level, while the bottom is maintained at 15 ft. 4½ in. above top of rail.

The skylights are of wire glass set in Monel metal sash, and cover 16% of the entire train shed area. The total area of the smoke duct is 15% of the train shed area; so that light is admitted through 31% of the roof area.

The train shed roof is of concrete with American Steel and Wire Company's triangular mesh reinforcement. The minimum thickness of the concrete is 2½ in., increased where necessary to secure proper drainage. Over the top of the concrete is a composition roof of the Johns-Manville system, consisting of asbestos felt laid in an asphaltic compound.

Along the Clinton street side the walls of the first smoke duct are extended up higher than the other ducts and the space between the duct wall and the building wall roofed over to form a gallery in which to carry the steam heating pipes and electric cables from the power house north of Lake street to the station building. It was only necessary to extend up one of the smoke duct walls to form this gallery, but the other one was also extended up to prevent the wind from producing down drafts in the duct. The total height of this duct is 12 ft. 3 in.

Longitudinal expansion is provided for at two intermediate points, one over Washington street and the other over Randolph street. Sections A-A and B-B show the methods of providing for expansion in the column struts and smoke duct struts respectively. The column strut slides on the top of the curved bracket, to which it is bolted through slotted holes, while the smoke duct strut is hung at the expansion end by links. Longitudinal expansion is also provided for where the train shed joins the main station building wall. Here the girders connecting the train shed to the building are supported by links suspended from steel columns in the building wall.

TRACK FLOOR.

The track floor construction in the train shed consists, in general, of a row of columns under the center of each track, supporting double web cross girders, or floor beams, through which the supporting columns pass and to which they are riveted. Two plate girder stringers support each track—one under each rail. The bottom flange angles of the floor beams are turned out and the top flange angles turned in. This arrangement was to facilitate erection work.

Connected to the ends of the track floor beams are similar double web girders supporting the train shed column and platform. These girders have both flange angles turned out. Under intermediate platforms they are set higher up than the track floor beams, except in a few particular cases where details were controlled by local conditions. No moment is transferred at the connection of these beams; but the floor beams under the outside platforms were made the same depth as the track floor beams, set at the same elevation, and the end connecting with the single track floor beam was spliced for the moment due to unbalanced dead load on the latter.

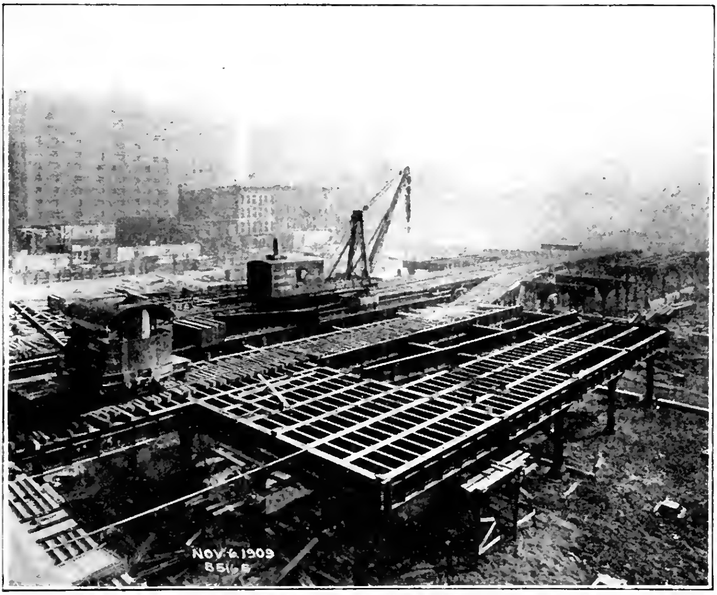


Fig. 7.—Construction of Track Floor in Station Yard.

The ends of the track floor beams carry shallow curb girders supporting the ends of the transverse I-beams carrying the platform slab. A similar longitudinal girder, connected to the platform floor beams, supports these I-beams at the center.

The track stringers and the curb girders are connected together laterally, between the floor beams, by lines of 12 in. I-beams spaced about four ft. apart. The tops of these I-beams are set 1 in. below the tops of the floor beams and track stringers and divide the track floor area into a series of rectangles. Shelf angles are riveted to each side of the stringer webs, and to the outside of the floor beam webs, flush with the bottom of the 12 in. I-beams. The shelf angles and the bottom flanges of the I-beams form the support for the concrete of the track floor, which extends above the top of the steel work from 1½ in. to 4½ in. according to drainage requirements. Each rectangular block of concrete is reinforced with rods in each direction and designed to support a wheel load in case of derailment.

The columns supporting the track floor are H sections, built up of two 15 in. channels with flanges turned in and connected by a web composed of one plate and four angles. The columns are all 12 in. wide out to out of channel webs and fit close between the webs of the floor beams. A plate bracket is riveted to either side of the column with a top angle connected to the bottom flange angle of the floor beam to give lateral stability to the structure. The columns are supported on cast iron shoes which rest directly upon the concrete foundations.

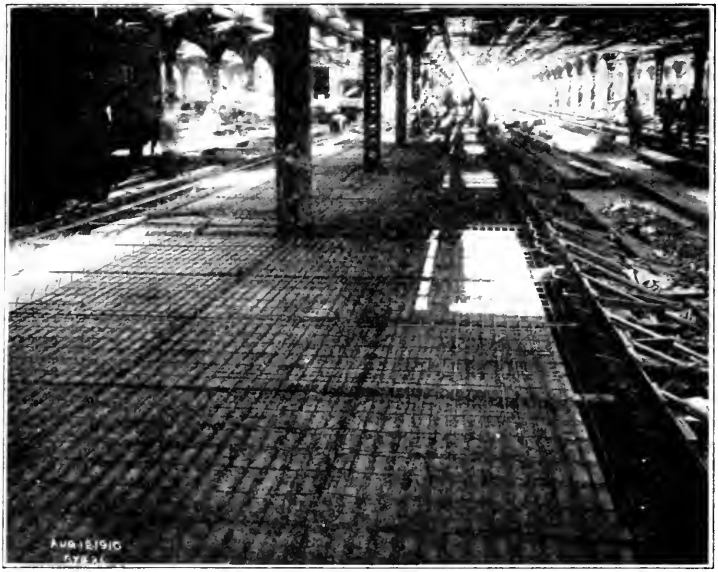


Fig. 8.—Platform Construction in Train Shed.

The platform I-beams are spaced about four ft. apart, and carry a concrete slab reinforced with Clinton wire cloth. This slab is 4½ in. thick at the curbs and 5½ in. at the center, a slope of one inch being given for drainage. An angle is set along the edge which is anchored into the concrete and forms a finish to the curb. The curb is 5 ft. from the center of the track and 8 in. above top of rail.

Longitudinal expansion is provided in the track floor at the same points as in the train shed previously described. The track stringers are supported in saddles at the expansion points, with provisions for sliding, which provisions are also made in the curb and platform girders. Sliding plates are introduced at the bottom of the concrete slabs, and an opening left in the concrete over these plates which is filled with a compressible asphalt mastic. No special provision was made for lateral expansion.

An interesting feature of the track floor construction is the method of supporting and fastening the rails, shown in Fig. 9. On account of the occupation of the space under the track floor, it was desirable that the noise from moving trains be reduced as much as possible. It was thought that this could be most effectually accomplished by supporting the rail on a cushion of wood. This method would also provide an insulation of the rail from the steel work of the floor, which was necessary. An 8 in. by 16 in. fir timber, dressed to 7½ in. by 15½ in., was placed flatwise on top of the track stringer to which it was fastened with hook bolts. Cast iron sockets extending under the flange angles of the track stringers, were placed in the concrete, so that the heads of the hook bolts could be introduced after the concrete was set. By this device the timbers can be removed and replaced with new ones at any time, without disturbing the concrete.

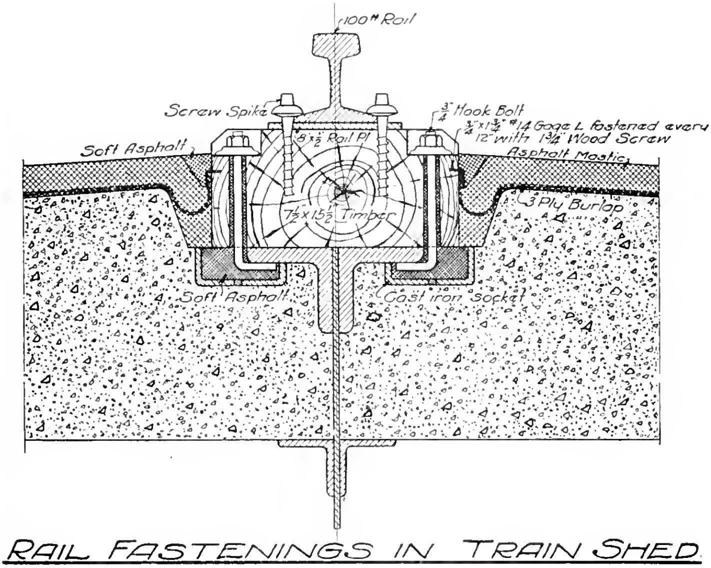


FIG. 9.

In order to prevent any leakage of water through and underneath the timbers, they were laid in a heavy mopping of hot asphalt spread upon the top flange of the stringers—the hook bolts having been first placed in position in the cast sockets and the timbers set down over them. The holes in the timbers were bored one-quarter of an inch larger in diameter than the hook bolts and the space around each bolt poured with hot asphalt. The bolts were then drawn tight while the asphalt was still warm.

The general style of construction between the north end of the train shed and Lake street, where the tracks are ballasted, is similar to that in the train shed except that the columns and stringers are placed at regular intervals instead of being located with reference to the tracks. The floor beams are of the same type and the stringers are connected together laterally with 12 in. I-beams which are concreted in the same manner as in the train shed.

Waterproofing.

All waterproofing was done with asphalt and asphalt mastic. The description of waterproofing work which follows applies not only to the track floors and platforms in the station yard, but also to the waterproofing of all viaduct floors over streets and alleys in the terminal territory. All waterproofing was laid on concrete surfaces. The concrete was allowed to become thoroughly dry before any waterproofing material was applied.

There were three classes of waterproofing work each differing from the others in certain particulars:

(1) On passenger platforms in train shed.
(2) On tracks in train shed, being the space between platforms.
(3) On ballasted track floors.

(1) Waterproofing on passenger platforms consisted of an asphalt mastic coating 1½ in. thick on top of the concrete of the platforms to serve as a wearing surface in addition to its waterproofing qualities. The concrete was first given a coat of liquid asphalt paint applied cold. The mastic used was the manufactured product of the Standard Asphalt and Rubber Co. It was brought on to the work in blocks and melted in specially designed boilers with the addition of a small percentage of flux.

After the mastic was thoroughly melted and mixed with the flux, grit, in the form of washed torpedo gravel or granite screenings, was added to the mixture, the amount of grit varying from 50 to 60% of the mass. The mixture was thoroughly stirred with iron stirring rods and brought to a temperature of 450 deg. F. It was then spread over the surface of the floor and rubbed down with wooden floats. The mastic was applied in two layers, each ¾ in. thick. The first layer was mixed with torpedo sand and the second layer with granite screenings, to reduce the slipperiness of the surface. The second layer was sprinkled with fine sharp sand while still warm and soft and thoroughly rubbed to a true smooth surface.

On top of this dry Portland cement was sprinkled and the rubbing continued until the mastic had quite hardened.

(2) Waterproofing tracks between platforms differed materially from the work on platforms, for the reason that the waterproofing character of the work was the principal feature while its character as a wearing surface was of secondary consideration. The track space is exposed to all the storm water coming through the smoke ducts in the train shed roof in addition to the drip from engines and cars.

The concrete was first painted with the cold asphalt paint. Over this was then spread three layers of 8 oz. burlap. Each layer was laid on a fresh mopping of hot asphalt and another mopping was applied on the top after laying. The entire thickness of this 3-ply coat of burlap and asphalt was ¼ in. The asphalt used for this purpose was required to conform to the following specifications:

"Asphalt shall be used which is of the best grade, free from coal tar or any of its products, and which will not volatilize more than one-half of one per cent under a temperature of 325 deg. F. for seven hours."

"It must not be affected by a 20% solution of ammonia, a 25% solution of sulphuric acid, a 35% solution of muriatic acid, nor by a saturated solution of sodium chloride. It should show no hydrolytic decomposition when subjected for a period of ten hours, to hourly immersions in water with alternate rapid drying by warm air currents."

"The asphalt must not flow under 212 deg. F. nor become brittle at 0 deg. F. when spread thin on glass."

"A mastic made from the asphalt by mixing it with sand must not perceptibly indent when at a temperature of 130 deg. F. under a load of 20 lb. per sq. in. It must also remain pliable at a temperature of 0 deg. F."

The method of sealing the joint between the waterproofing and the wooden sleeper supporting the rail is shown in Fig. 9. A groove or channel was formed in the concrete alongside of the timber. The bottom of this groove was first filled with mastic, the top of which was finished with a curved surface. The burlap was then folded down into this groove and up along the side of the timber. The edges of the burlap were cut off to line and held against the timber by a ¾ in. by 1¾ in. metal angle ⅛ in. thick, the ¾ in. leg of which was sharpened and driven into the timber, after first having scored the wood with a chisel. The 1¾ in. leg of this angle was pressed tightly against the burlap and held in position by wood screws through it into the timber, the screws being spaced 12 in. apart.

Over the surface was then spread 1½ in. of mastic in two layers, each layer being mixed with torpedo sand the same as the first layer on the platforms. The second layer was finished by rubbing with sand and Portland cement, the same as before explained.

Before spreading the mastic, however, a strip of wood 1 in. thick was placed along the side of the timber. The wood strip was drawn out after the mastic had hardened and the space filled with a hot pure asphalt of low melting point. This material will remain pliable to some extent at the lowest temperature and will more effectually seal the waterproofing to the timber.

(3) Waterproofing track floors under ballast was done in practically the same way as the tracks between platforms, except that a sand mastic was used in place of the manufactured mastic, and the finished layer was swabbed with hot asphalt instead of being rubbed with sand and Portland cement.

The sand mastic was made by heating asphalt of the same grade as that used for laying the burlap, and mixing it with fine clean sand in the proportion of about one to four, and bringing the mixture up to about 450 deg. F. A sand considerably finer than torpedo was used, or a graded sand in which there was a considerable amount of fine material.

Contractors.

All steel work for the track floor and train shed was furnished by the American Bridge Co. and was erected by the Strobel Steel Construction Co. The foundations and the concrete of the track floor were placed by George W. Jackson, Inc. The mastic work on platforms and the waterproofing of the track floor was done by the Standard Asphalt and Rubber Co.

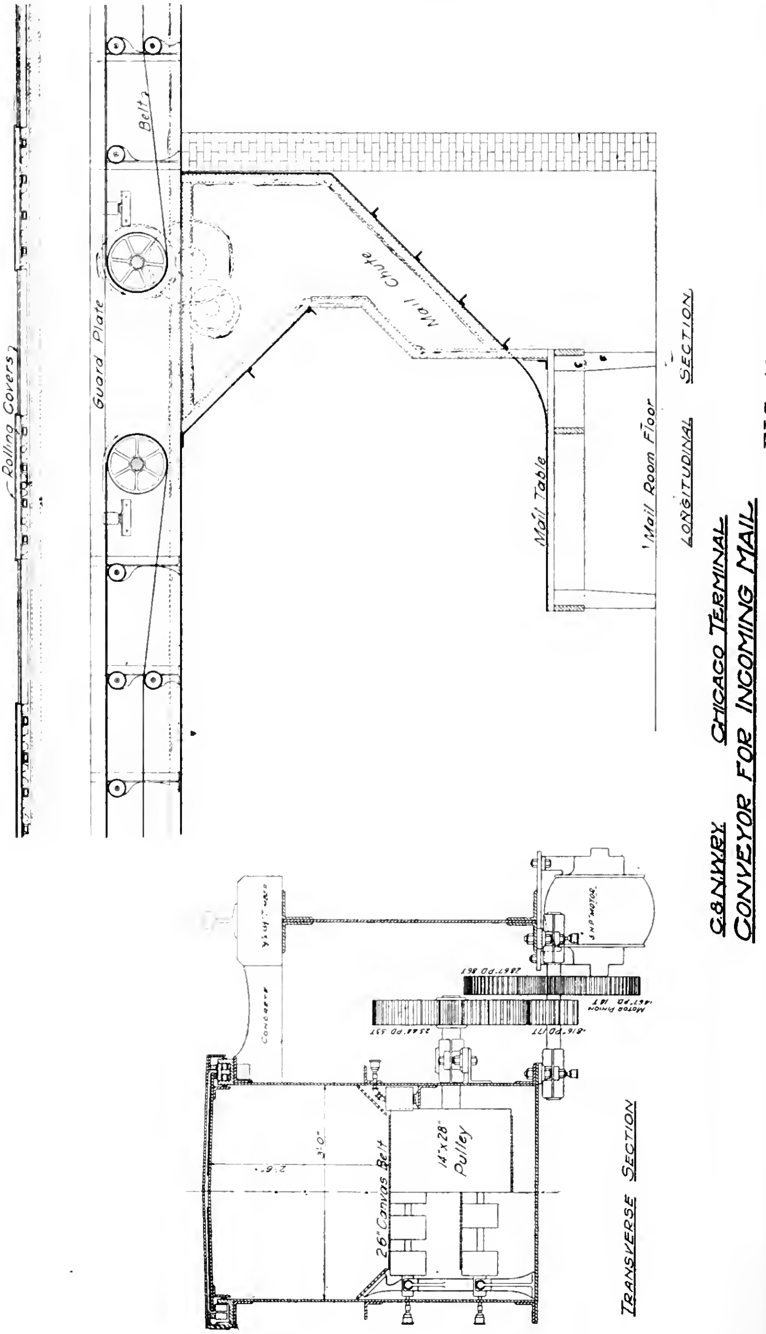
MAIL CONVEYORS.

A great deal of study was given to the question of eliminating trucking from the platforms, in order that they might be devoted as fully as possible to the unobstructed use of passengers. The complete accomplishment of this object would have required that all baggage, and mail carried on passenger trains be handled by some other means than the customary truck. As the cars carrying these classes of matter are drawn at the head of the train, generally next to the engine, the question of eliminating the use of the trucks in loading this material was not so essential, for these cars on outbound trains would occupy a position near the north end of the platform, beyond the coaches. Trucks raised to the track level through the north system of elevators could reach the cars without interfering with passengers on the platforms. It was only the question of unloading from incoming trains that called for any special study.

From a mechanical standpoint it would have been possible to handle either of these classes of matter by some form of power conveyor, installed between tracks, so that all unloading could have been done on the opposite side of the train from the platform. But for handling baggage in this way it would have required that the tracks be spread farther apart, and this would have resulted in either narrowing the platforms or reducing the number of tracks, neither of which was desirable. It was clearly impracticable to handle both classes of matter on the same conveyor at the same time; and handling one class at a time would have delayed unloading. So many difficulties were presented in any scheme of handling baggage by power that the proposition was abandoned. But a system of belt conveyors for unloading and transferring incoming mail was devised and installed.

The conveyors are located between tracks 4 and 5, 6 and 7, 8 and 9 and 10 and 11. Their location number and direction of travel are shown in Plate IV. The tracks between which conveyors are located are assigned to through trains carrying mail cars. There are six conveyors in all—four of them, Nos. 2, 4, 5 and 6 running northward, and two, Nos. 1 and 3, running southward, and all delivering into chutes leading to the mail distributing room below on the street floor. The four conveyors running northward are so located as to be abreast of the mail car, should it be either the first or second car from the engine, when the engine has reached a point near the end of track. The two conveyors running southward are for special conditions. If it should occur that the mail car was farther back than the second car from the engine, or if there should be other cars standing on the tracks, these two conveyors could be brought into use. Conveyors 4 and 5 are only extended far enough south to reach a mail car at its extreme southern position with the engine in front of it; while 2 and 6 extend southward clear to the end of track, and a chute is there provided leading to the conveyor at the extreme end. A great many of the suburban trains bring in a few pouches of mail. These trains enter the station on the shorter tracks near the Canal or Clinton street side. The mail pouches which they carry are thrown on a small truck or carried by a station employee and brought round to the end of conveyor 2 or 6, according to the side the train enters, and passed through the chute into the conveyor.

The details of the conveyor are shown in Fig. 10. A trench is formed in the track floor 3 ft. wide and about 4½ ft. deep. The floor beams, which at other points are continuous between tracks, are here made in two parts, the ends of which are separated by the width of this trench. The trench is formed of steel plates for the sides and bottom, the side plates being riveted to the floor beams and the bottom plate riveted to a flange angle on the lower edge of the side plates. The belt is of heavy oiled and stitched canvas 26 in. wide and carried on steel rollers located about 3 ft. apart. The rollers on the under or return side are about 9 ft. apart. The brackets for roller supports are bolted to the bottom plate of the trench. Guide rollers are placed on the sides of the belt supported on angle brackets bolted to the side plates of the trench, for the purpose of



C.&N.W.RY. CHICAGO TERMINAL
CONVEYOR FOR INCOMING MAIL

FIG. 10.

holding the belt in its proper position. Guide plates, set at an angle of 45°, are fastened to the tops of the roller brackets with counter sunk bolts, for keeping mail sacks in proper position on the belt. The belt is located 30 in. below the under side of the cover, so that mail sacks have a clear space for movement of 30 by 36 in.

The conveyor trench is covered with steel diamond floor plates ⅜ in. thick. They are in sections 4 ft. long, and with certain exceptions are made movable upon roller bearings. Each section telescopes the adjacent section, and when closed latch automatically. An entrance to the conveyor belt can be made at any point by means of these rolling covers, except where there would be no need for such entrance, in which case the covers are bolted in place and fixed in position. The fixed covers are located over the end pulleys of all conveyors and over that portion of conveyors 2 and 6 beyond the extreme possible position of a mail car with an engine in front.

Each conveyor is operated by a 5 H. P. 220 volt D. C. motor, directly connected, and geared to a speed of 300 ft. per min., which speed is attained in 10 seconds from starting.

The entire equipment was furnished and installed by the Stephens-Adamson Manufacturing Co.

WASHINGTON STREET TUNNEL APPROACH.

As previously stated, provision was made in the structural work over Washington street for the approach to the tunnel under the Chicago river. As originally constructed the descent into the tunnel began at the east line of Clinton street. The descending grade was 6.33%. The portal of the tunnel was on the west line of Canal street, the open approach extending from Clinton street to Canal street. The width between approach walls was 19.75 ft. The roof of the section under the river was 17 ft. below city datum, which, at the time the tunnel was remodeled in 1889, was practically the depth of water in the river. But on account of the lowering of the lake level and the reversal of flow of the Chicago river by the construction of the Drainage Canal by the Sanitary District of Chicago this depth was reduced to about 15 ft. at times. The obstruction to navigation caused by this shallow depth resulted in an order from Congress for the lowering of the top of this tunnel and also the tops of the La Salle street and Van Buren street tunnels. In compliance with this order the lowering of the top of the Washington street tunnel was completed in the spring of 1907. A new roof was constructed across the interior of the tunnel by inserting a series of parallel girders pocketed into and supported by the side walls, and encasing them in concrete, after which the original roof was broken up and removed.

The tunnel had been used by the Chicago Union Traction Co., for the passage of its cars under the Chicago river, but was put out of commission when work was begun on lowering the roof. In order to restore it to a state of usefulness it was necessary to extend the side walls by under-pinning, lower the floor to give proper head room below the new roof and reconstruct the approaches to conform to the lower grade of the river section. A plan for this work was prepared under the direction of the Board of Supervising Engineers and the work was carried out by the Chicago Railways Company.

The river section was constructed to give 26 ft. between side walls, the two street car tracks being carried through the same bore. But on the approaches the tracks were separated by a center wall and an arch turned over each track. This required a widening of the distance between the outside walls from 19.75 ft. to 29 ft., except that portion between Canal and Clinton streets where the clear width was made 26 ft.

In anticipation of a future system of city subways, of which this work would form a link, the approach was designed to meet the future conditions, and as much of the permanent work on that line was done as could be carried out at this time. An ascending grade of 2.9% on that portion between Canal and Clinton streets was established, bringing the top of rail to an elevation of —14.0 at the east line of Clinton street, 28 feet below street level. In order that the tunnel might be turned into immediate use it was necessary to construct the tracks on a temporary grade coming to the street level at Clinton street. This required a 9.0% grade and made it necessary to omit the arch roof over the greater portion of the space between the two streets. For a distance of about 60 ft. from Clinton street, where the temporary track construction cleared the top of the arch the center wall and arches were completed, but over the balance of the distance to Canal street, the arches were not built and the center wall was only carried up to the bottom of the temporary track construction for which it formed a support. A longitudinal section and cross section for this work are shown in Plate VIII. The temporary tracks are carried on wooden stringers supported upon reinforced concrete struts extending from and built into the side walls and resting upon the center wall.

The Chicago and North Western Ry. Co. coöperated with the Chicago Railways Co., to the extent of designing the structure supporting the station yard tracks and train shed in harmony with the plan for the tunnel approach, and also in building such portions of the side walls as it would have been necessary to build had the original tunnel approach been restored to its former condition. It was not considered advisable to support the track columns on the side walls of the tunnel. They were therefore carried down below the proposed future grade of the Chicago Railways Co.'s tracks, and rest upon concrete caissons sunk into the hard pan to an elevation of —70.0 or 84 ft. below street level. The caissons supporting track columns are 6 ft. in diameter, while those supporting the trainshed walls are 5 ft. They are all belled out at the bottom to give greater supporting area—the six-foot caissons to 10 ft. diameter and the five-foot ones to 8 ft. The columns are spaced 28 ft. apart in a direction at right angles to the axis of the tunnel, and parallel with the tunnel the spacing corresponds with the spacing of the station yard tracks.

The columns in each row are connected together below the street level by plate girders, set flatwise, to resist the lateral pressure of the earth in the roadways on either side of the tunnel approach. There are two lines of horizontal girders, the lower line being located just above the proposed extension of the tunnel arch, and is stepped down correspondingly with the descending grade of the arch. The upper line is horizontal and just below the street surface. The two lines of girders are connected together by vertical I-beams spaced about 3 ft. apart. The girders and I-beams are entirely enclosed in the concrete of the side walls of the tunnel approach. The purpose of the I-beams is to transmit the earth presssure to the girders which transmit it to the columns. The bending moment on the columns is relieved by steel struts composed of two latticed channels attached to the columns at or near the girder connections and extending across the tunnel opening, bracing the two lines of columns apart. When the steel work was first erected these struts were provided at each point of connection of the girders and columns in order to provide for the lateral thrust during the construction work on the tunnel approach. Certain struts were afterward removed where they would cause interference with cars on the temporary tracks, and the pressure transferred through bending in the columns to reinforced concrete struts built just beneath the temporary grade line. Provision was made in the design of the columns and in reinforcement placed in the concrete side walls below the lower horizontal girder to take care of this bending.

All the concrete below the lower horizontal girders, except the caissons, was placed by the Chicago Railways Co. That above these girders was put in by the C. & N. W. Ry. Co. Geo. W. Jackson, Inc., was the contractor for the work executed by each company.

POWER HOUSE.

The power house is located on the triangular plat of ground bounded by Lake street, Clinton street and Milwaukee avenue. It is divided into four compartments—a boiler room, engine room, machine room and pump room. The arrangement of these compartments is shown on the foundation plan, street floor plan and track floor plan—Plates VI, III and IV, respectively. The floors of all these rooms are considerably below the street level. The elevation of the boiler room and pump room floors is —6.58, that of the engine room and the machine room floors +3.75—the elevation of the street being +14.0. Underneath the boiler room floor is the ash pit, the floor of which is at elevation —20.00. The enclosing walls of these rooms up to the street level are of concrete, built very massive to resist the earth pressure. The wall along Milwaukee avenue, that along the east side of the pump and machine rooms and the one along the south side of the machine room carry the brick walls enclosing these rooms, and in addition the track columns on these lines. The track floor forms the roof over the pump and machine rooms, and consists of rectangular troughs filled with concrete and waterproofed—the construction being similar to that of the street viaducts which will be more fully described later.

The walls of the boiler and engine rooms extend above the track level to a height of 51 ft. above the street. The north and south end walls and the west wall of the engine room are supported on the retaining walls, while the east wall of both rooms and the west wall of the boiler room are supported on columns, whose foundations are below the floor levels. The walls on the street lines have a granite base extending up to the window sills, surmounted with brick—the facade being of a grey colored face brick, the entire order harmonizing with the walls of the train shed south of Lake street.

The chimney is located at the northwest corner of the power house. It is 226 ft. high above the street level. The internal diameter at the base is 11 ft. and at the top 10 ft. 6 in. The base is octagonal to a height of 57 ft. above the street—the short diameter of the octagon being 20 ft. 4 in. at the base and 18 ft. 8 in. at the top. The shaft above is circular with an external diameter decreasing from 18 ft. at the top of the octagonal base to 13 ft. 6 in. at a point 17 ft. 3 in. below the top. The top is widened to 17 ft. 6 in. and is capped with a circular iron casting. The foundation is a concrete slab 7 ft. thick and 22 ft. square supported upon four concrete caissons 6 ft. in diameter and founded on rock. The octagonal base is common brick with a grey brick facing and terra cotta trimmings. The circular section is built of the Custodis radial brick of a color to harmonize with the base and the power house walls. The lining is of fire brick 8 in. thick at the bottom and 4 in. at the top. It is built free from the main walls and is divided into four sections. Each section is supported upon a ledge corbeled out from the main wall. Each section therefore expands independently of the others.

The excavation was made and the foundations built by Geo. W. Jackson, Inc. The building was erected by the Geo. A. Fuller Co.

ELEVATED APPROACHES.

As explained under the head of General Description, the new approaches are elevated from the station building to the points where they connect with the original elevated tracks. The elevated district, or the district in which grade crossing have been entirely eliminated from passenger service tracks, at the present time is as follows:

Galena Division:	
From the new station to the Soo Line crossing at River Forest	9.7 miles
Wisconsin Division:	
From the new station to Clybourn Junction	3.0
Clybourn Junction to Mayfair station on the Mayfair line	4.7
Clybourn Junction to Oakwood Ave., Wilmette, on the Evanston line	11.0
Total	28.4 miles

The elevation of the new approach tracks above the level of the streets is much greater than that of other elevated tracks generally in the city. This is due to local conditions. By referring to Plate I. it will be seen that the approach tracks cross over the tracks of the P., C., C. & St. L. Ry. Co. on Carroll Ave., and over the Galena Div. tracks in Kinzie St. By agreement with the P., C., C. & St. L. Ry. Co. a clear head room of 21 ft. was given over their tracks, and it was not desired to have a less head room over the tracks in Kinzie St. Furthermore, the conditions governing the design of the structure over the P., C., C. & St. L. Ry. tracks required a considerable depth of floor. This structure will be described in more detail later.

The distance from the top of the P., C., C. & St. L. Ry. rail to the top of the C. & N. W. Ry. rail is 25.9 ft.; and this is practically the height of the elevated tracks above the street level from Carroll avenue to Jefferson street. Going west from Jefferson street, the West Approach tracks cross over the street viaduct approaches on Des Plaines street, Milwaukee avenue, Halsted street and Sangamon street, which are all elevated at the points of crossing several feet above the original level of the streets. These viaduct approaches are descending to the northward from Kinzie street and reach the general level of the streets in this territory midway between Austin avenue and Grand avenue. As the ordinance required a minimum clear headroom on each of the streets where the viaduct approaches were crossed of 14 ft., it will be seen that these were the points that determined the elevation of the grade, and at other adjoining streets the grade would be much higher than necessary for the required headroom of 14 ft.

On the North Approach the elevation of the grade was fixed at Chicago avenue, where the crossing again occurred on the street viaduct approach, and a minmum clear headroom of 14 ft. was required.

From the south line of Lake street to the west line of Jefferson street, 71% of the track area is on steel structures. Retaining walls with sand filling were constructed only where the space underneath the tracks could not be profitably utilized.

On the West Approach all tracks are on sand filling except the street and alley viaducts. These comprise 25% of the entire track area. A continuous retaining wall (except at the streets and alleys) is built from Jefferson street to Elizabeth street along the south line of Austin avenue. This forms the north wall supporting the elevated tracks. A view of this work is shown in Fig. 11. On the south side of the tracks retaining walls were only built where sufficient right of way was not secured for the slope of the sand filling.

The North Approach, cutting diagonally across all street and property lines, was much more irregular in construction. Generally the slopes of the embankment were run out the full distance and a light concrete wall was built at the toe extending 8 ft. above the surface of the ground to serve as a barrier wall and property fence. The abutments were extended out and tapered down to connect with these light walls. A view of this construction is shown in Fig. 12.

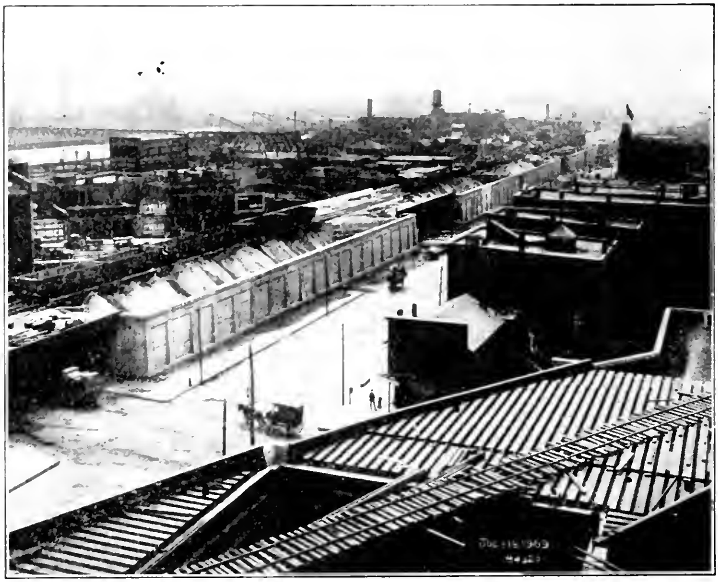


Fig. 11.—West Approach Concrete Retaining Wall, South Side Austin Ave.

Retaining Walls.

Retaining walls are of the gravity type and built of concrete. The ordinance permitted the footings of all retaining walls on street lines to be projected four feet into the street. This made it possible to design a wall in which the center of pressure fell very near to the center of the base. For walls of medium height the base is about 60% of the height. But as the four-foot projection of the toe is constant this ratio could not be maintained for the high walls without increasing the slope of the back or unduly projecting the heel. Therefore this ratio decreased as the height of wall increased, but in no case was it made less than 50%.

The back of the wall was stepped. The height and width of steps remained constant, so that walls of different height were alike except for the number of steps and the dimensions of the base. An elevation and cross section of one of the highest retaining walls is shown in Fig. 13.

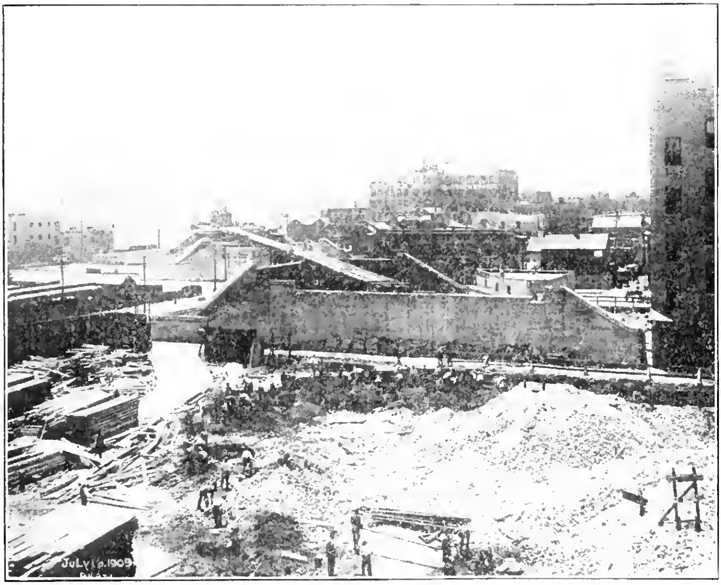
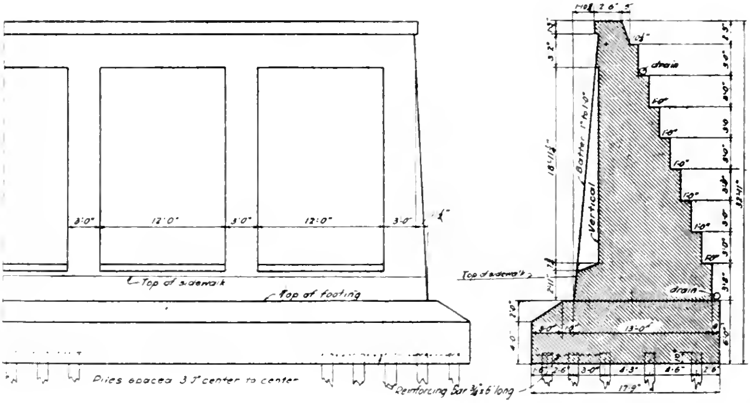


Fig. 12.—North Approach, Retaining Walls and Abutments.

In order to relieve the monotonous appearance of a plain concrete wall, the face was divided into panels separated from each other by broad pilasters. The top of the panel is a uniform distance of 4 ft. 3 in. below the top of coping. The bottom of the panel forms a ledge in the wall a few inches above the sidewalk. In perspective the face of wall presents the appearance of a series of columns. The panels, aside from the feature of ornamentation, are also economical; for there is a saving of from 5 to 10 cubic yards of concrete in each, depending upon the height of wall, which much more than compensates for the additional cost of forms.

The material upon which all the walls are founded is blue clay, characteristic of the clay which underlies the entire city. It was the aim in designing the walls to keep the maximum pressure down to 3,000 lb. per sq. ft., but in case of the very high walls this limit was slightly exceeded. Piles were driven under the entire foundation, varying from 24 to 30 ft. in length, the longer piles being placed under the toe. The outer row was placed 1 ft. 6 in. from the toe of the footing and the next row under the neat line of the super-wall. The spacing of the remaining rows was greater, depending on the width of base. Four rows of piles were driven where the width of base did not exceed 15 ft. and five rows where the width of base was greater than 15 ft. Piles were spaced 3 ft. apart longitudinally. It was designed to keep the pressure per pile down to 15 tons each, wherever practicable, though in some cases the calculated pressure ran as high as 18 tons. The difficulty in driving a large number of piles closely spaced had to be taken into consideration. Even with the spacing adopted there was considerable heaving of the foundation material as the driving proceeded.



C&N.W.RY. CHICAGO TERMINAL
TYPICAL RETAINING WALL

FIG. 13.

The projecting toe of the foundation was reinforced with 3¾ in. twisted square steel bars 6 ft. long in each space between piles.

The concrete in the first walls that were built, was made of crushed and washed gravel and torpedo sand; but as the work was carried on through the winter, and the washing plants shut down, it became necessary to use a different material and one that could be readily obtained in large quantities. It was therefore decided to use pit-run gravel, a very good quality of which could be obtained in the Fox River district in unlimited quantities. This gravel ran about 60% torpedo sand—a much larger proportion than would have been used had the materials been separated and afterward mixed. It was therefore necessary to use a greater amount of cement. The mixture used contained about two barrels of cement per cubic yard of concrete. So satisfactory did this prove, both in the matter of economy and facility of handling, that the use of pit-run gravel was continued throughout the entire construction work. The increased amount of cement used was compensated for by the cheaper cost of the other materials.

In the matter of handling, there was a great advantage in the use of pit-run material. Reducing the materials to one unit simplified the methods of work, and the arrangement of the working plants. It simplified the transportation and reduced the liability of delay for want of the proper materials in the proper proportions. So long as there was any material on hand it was the right material. The element of transportation is one of great importance where work is being done in a territory of congested traffic.

The walls were built in sections 30 ft. in length. The footings were first built and allowed to set. The forms for the super-walls were then built. It was required that an entire section of super-wall should be poured at one continuous run of the mixing plant, in order that no horizontal joints might occur in the walls. This required that the forms be very substantially built. The forms were constructed with 4 in. by 6 in. studding and 2 in. by 8 in. dressed and matched sheathing. The two sides were tied together with ⅞ in. rods which were passed through iron pipes consisting of old boiler flues. The rods were drawn out when the forms were removed, but the pipes were left in place, the openings in the faces of the wall being filled with mortar.

Abutments for street and alley viaducts were similar to the retaining walls, except that there was no projecting coping.

Drainage.

A system of drains was provided along the backs of all retaining walls and abutments. A six in. tile drain was laid around the entire back of the walls at approximately the original ground level, which was usually at about the top of the footing. In addition to this, a four in. tile drain was laid on the back of all abutments, usually on the first step from the top. Broken stone filling only was used over the top of this drain and extending up to the track ties. In many cases a drain at the same elevation was carried around on the retaining walls also. All of these tile drains were carried to manholes built of concrete in the angles between the abutments and the retaining walls. The manhole had two sides formed by the retaining wall and abutment. The other two sides were concrete 12 in. thick. The manholes were 3 ft. 6 in. square inside (covered at the top of the walls with a cast iron plate set in a cast frame) and extended down to within one foot of the bottom of the wall footings, where a connection was made with the city sewers by a 12 in. pipe extending through the abutment and under the sidewalk. A ladder was provided for descending into the manhole by building ¾ in. rods into the concrete across one of the corners.

Contract Work.

All concrete work was done by contract. The work on the Terminal Section and including the foundations for the station yard and trainshed was done by George W. Jackson, Inc.; that from Jefferson to Halsted street on the West Approach and all of the North Approach was done by the Bates and Rogers Construction Co.; while that part of the West Approach west of Halsted street was done by J. J. O'Heron & Co.

All material for work on the Terminal Section and Station Yard from Jefferson street to Halsted street on the West Approach and from Jefferson street to Phillips street on the North Approach was delivered on cars in the team yard between Kinzie street and Jefferson street and hauled by team to the point used. West of Halsted street and north of Phillips street material was delivered on a temporary elevated track about the center of the right of way on each approach.

Concreting Plants.

Some interesting plants were designed and constructed by the various contractors for hoisting and conveying concrete and concrete materials. For constructing the walls between Milwaukee avenue and the P., C., C. & St. L. Co.'s property a cable was erected by Geo. W. Jackson, Inc., supported on anchored towers, one located in the triangle between Lake street and Milwaukee avenue and the other located in the driveway just south of the P., C., C. & St. L. Ry. freight house. The entire towers and their anchorages were supported on car wheels and track which permitted of their being shifted east and west to reach either the east or west wall or any part of the intervening abutments. The device worked well, but it was not economical, and its capacity was too limited. The best average rate obtained in 8 hours was 24 cubic yards per hour.

For the work between the P., C., C. & St. L. Ry. property and Jefferson street the concrete was mixed at the ground level, hoisted to the top of the wall in a drop bottom bucket by a stiff leg derrick, dumped into a hopper, from which, by opening a gate it was poured into a dump car which was pushed by hand to the proper place on the wall. A track, of course, had to be built over the top of the forms to be filled. This device was more economical than the cable, as the work of installing and moving was considerably less. An average rate of 33 cubic yards per hour for 8 hours was the best record.

The plant erected by the Bates and Rogers Construction Company consisted of an elevator tower, framed in wood, extending from the street level to a height of about ten feet above the top of the wall, through which an elevator bucket was operated by a hoisting engine at the street level. This bucket was arranged to dump automatically, when it reached the top, into a dump car which was pushed by hand along and above the top of the wall. The concrete mixer was mounted a little above the street level so as to discharge into the elevator bucket when it was at the bottom of the tower. The material was fed into the concrete mixer from a hopper, placed a little higher than the mixer, through a gate operated by hand. The gravel was brought to the mixing plant in drop bottom wagons. In the first plant of this kind installed a stiff leg derrick was erected which lifted the wagon box off the trucks, hoisted it up above the hopper, into which the contents were dumped. In all subsequent plants erected where the material was delivered in wagons, an incline was built, up which the wagon was drawn by a cable after the team had been removed. The contents were dumped into the hopper and the wagon lowered to the street again by gravity. This method of elevating the material was found to be more satisfactory than the former.

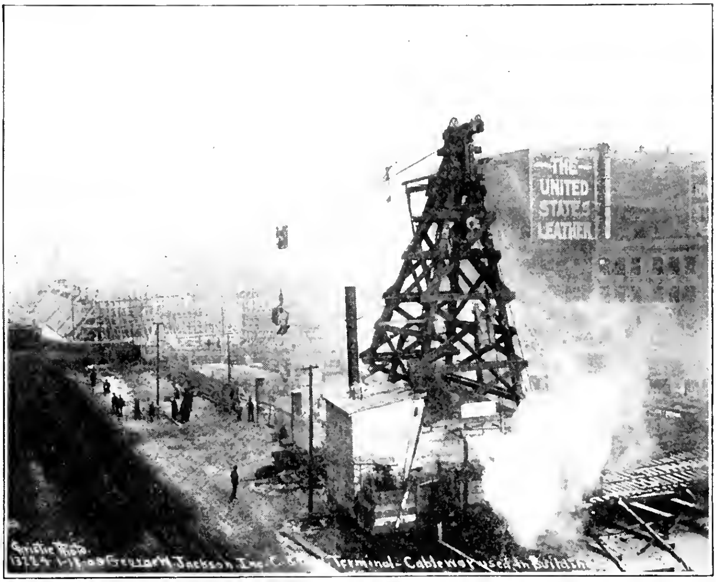

Artistic Photo.
13224 1-18-09 George W. Jackson Inc.
Terminal - Cableway used in building
THE UNITED STATES LEATHER

Fig. 14.—Geo. W. Jackson, Inc., Cableway for Handling Concrete.

The operation of this plant was successful in every respect. The best average rate in 10 hours was 37 cubic yards per hour.

December, 1911

The concrete was transported by the dump cars in some cases as far as 500 ft. from the mixing plant. For depositing the concrete in foundations it was transported on the track above the top of the wall as far as the forms were built and the elevated track supported on the forms was constructed; at which point it was dumped into a chute which delivered it into another dump car running on a track at the ground level.

The method adopted by J. J. O'Heron & Co. consisted in the use of portable concrete mixers, rigged with the ordinary power-hoist charging bucket. For pouring the foundations the mixers were used at the street level. The gravel used on this work was delivered in side swing cars on the temporary track, previously referred to, which was elevated about 20 ft. above the street level. The gravel was dumped from the cars to the ground and carried to the charging buckets in wheelbarrows, in the usual way. The mixers discharged into sheet metal troughs or chutes which poured the concrete directly into the pit. In some cases the same machines were used on the super-walls by elevating them above the top of the walls so the chutes would deliver at the top of the forms. When the mixers were in this position the material was either dumped from the cars upon platforms or shoveled directly into the wheelbarrows.

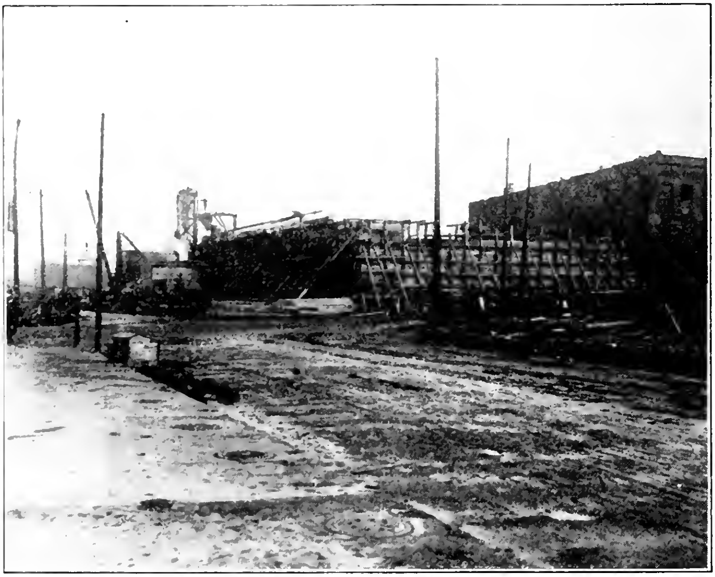


Fig. 15.—Concreting Plant of Bates & Rogers Construction Co.

A considerable portion of the long straight wall along the south side of Austin avenue was built with a specially designed wall machine, which consisted of a power mixer mounted on a heavy portable truck, with a power-hoist charging bucket, and in addition a power-hoist elevating bucket. The charging bucket was filled in the usual way. The mixer discharged into the elevating bucket which was attached to a steel frame guide leading to the top of the wall, where the bucket dumped automatically. The elevating bucket was operated by a steel wire cable attached to a drum on the engine which ran the mixer and which was mounted on the platform alongside of the mixer. The machine did some effective work, but it was too unwieldy to be generally satisfactory. The principal objection to it was that it could not be moved along close to the wall without interfering with the form bracing. It did not require as large a crew to operate it as was required with some of the other plants; the reduction in force being due to the direct delivery of the mixed concrete into the forms, without the use of dump cars and the men necessary to operate them. The best result secured was a rate of 25 cubic yards per hour.

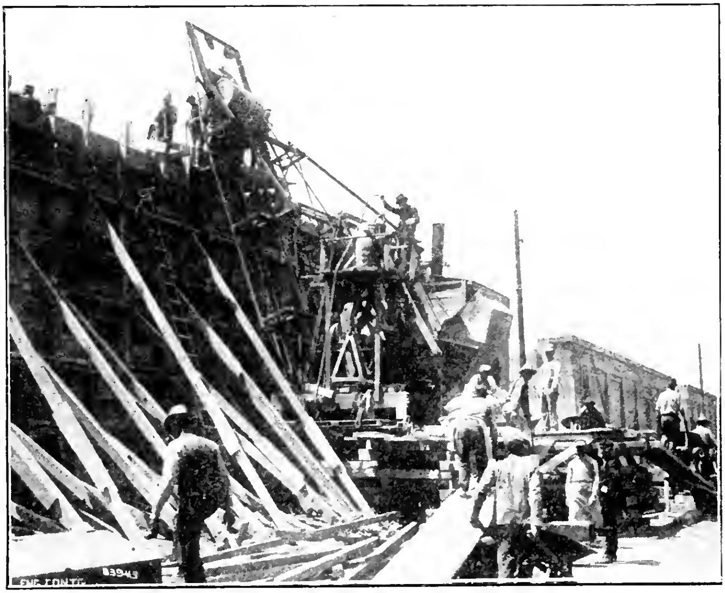


Fig. 16.—Concreting Plant, J. J. O'Heron, Special Wall Machine for Mixing and Hoisting.

In making these comparisons of the different plants and their efficiency it must be remembered that the conditions were different in each case. The manner in which the material was delivered on cars, whether at the site of the plant or at some distance away, whether on the elevated temporary track or on some surface track; the number of cubic yards that could be placed from one setting of the plant, involving the question of frequent installations of the plant or a longer haul of the mixed concrete; the distribution of the volume of concrete, whether in a continuous heavy wall or in isolated abutments and piers; all these had to be taken into account in determining the kind of plant best suited to the conditions. It must therefore not be inferred that any unfavorable comparison is a reflection upon the judgment or ingenuity of the contractor; for each had different conditions to meet and each was designed to meet the conditions peculiar to that part of the work.

It might be stated as a general principle in the design of concreting plants that the capacity of the mixer should be made the determining factor in the output. The charging, hoisting and conveying appliances should be designed with such a degree of flexibility as to preclude the possibility of retarding the mixing process by delay in charging the mixer or delay in removing the discharged concrete. The most economical mixer, other things being equal, is the one which discharges its mixed batch and receives its new batch in the shortest time.

Street Viaducts.

The type of street viaduct constructed follows very closely the standard adopted by the C. & N. W. Ry. Co. several years ago for track elevation work. It consists of transverse plate girder beams supported on rows of columns in the curb lines and in the center of the street and supporting rectangular trough section floors. The troughs are laid longitudinally and are filled with concrete to a few inches above the top of the metal and a waterproof coating is spread over the top of the concrete extending part way down the back of the abutment. They are deck structures throughout. The only metal projecting over the floor are the facia girders on the sides. These serve to retain the ballast and form a finish to the sides of the structure. They carry very little dead load and no live load, except on skewed crossing where they generally carry the beveled end of the short triangular sections of the trough floor.

On square crossings trough floor construction is very simple, but on skewed crossings it sometimes becomes very complicated; particularly is this true in crossings over the intersections of two streets. It is difficult work to erect where the troughs frame into the supporting girders. One end of the trough section can be framed into the supporting girder and the work erected quite easily if the other end rests on top; but where it would have been necessary to frame in each end another type of floor was adopted. For this reason several of the viaducts on the North Approach were of special construction. On the West Approach, however, nearly all the crossings were square and the trough floor type was used throughout.

A general elevation and typical details of this viaduct are shown in Plate IX. It shows a 66 ft. street with 14 ft. sidewalks. The roadway spans are 20 ft. 6 in. and the sidewalk spans 14 ft. 6 in. The troughs over the sidewalk being shallower than those over the roadway afford a ready means of sloping the surface of the concrete from the center of the viaduct to the abutment, for drainage, without making the concrete excessively thick at any point.

Ordinarily the webs of trough constructoin are placed equal distances apart, but a departure from the practice was introduced and the webs were spaced 10 in. apart for openings from above, which were filled concrete, and 18 in. apart for openings from below. The top cover plate was, therefore, wider than the bottom plate, but the bottom plates were made correspondingly thicker than the top plates so that the section remained symmetrical with respect to its neutral axis. The advantages of this arrangement were:

(1) A saving of concrete and reduction of dead weight.

(2) Greater facility for inspection and painting the under side of the floor, particularly where deep troughs were used, and

(3) Better opportunity for effective field riveting in the connecting diaphrams.

There was another advantage in these structures; the large spaces afforded more room for carrying through underneath the floor numerous steel pipe conduits for electric cables used in connection with the signal and interlocking system and for telephones, electric lighting, etc., as shown in the figure referred to. All steel work for street viaducts was furnished by the American Bridge Co. and erected by the Strobel Steel Construction Co.

Alley Viaducts.

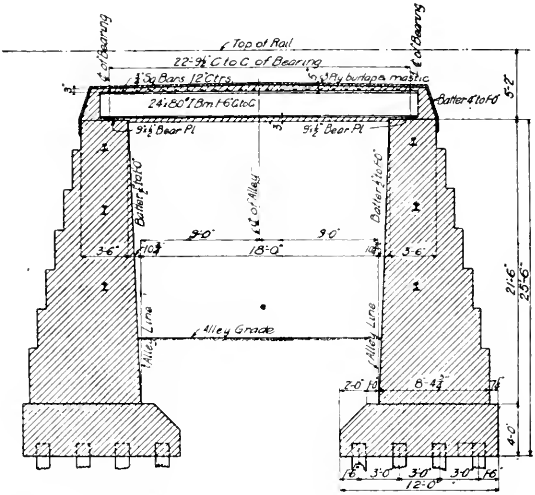
The alley viaducts, a section of which is shown in Fig. 17, are simply I-beam culverts. The abutments are similar to the street viaduct abutments. The floor is formed of 24 in. I-beams spaced 18 in. between centers. They are completely enveloped in concrete, the concrete extending 3 in. below the bottom flanges and 3 in. above the top flanges at the ends and 5 in. at the center. The three outside beams on each side are connected together with tie rods, and the entire structure is tied together laterally by ¾ in. bars laid 12 in. apart on top of the I-beams. The surface of the concrete is waterproofed in the same manner as the street viaducts.

SPECIAL CONSTRUCTION.

Structure Over P. C. C. & St. L. Property.

A steel structure, involving some interesting features, was designed to span Carroll avenue and the P. C. C. & St. L. Ry. property lying immediately south of it, a distance of 235 ft. between abutment walls. The P. C. C. & St. L. Ry. property includes two main-line tracks occupying the south half of Carroll avenue, four freight-house tracks, a freight house and a team-way. The location of this property is shown in Plate I. The main line tracks of the P. C. C. & St. L. Ry. west of Clinton street are straight, but curve to the southward on 18° curves east of Clinton street. The house tracks and the freight house are on curves concentric with the main lines. The C. & N. W. Ry. terminal tracks are straight, south of Carroll avenue, but northward from the south line of Carroll avenue they curve to the west—the center line of the six track system being on a 7° 30′ curve.

By agreement with the P. C. C. & St. L. Ry. Company the freight house was rebuilt under the C. & N. W. Ry. structure—the floor of the elevated structure forming the roof of the freight house. The team-way south of the freight house and the tracks north of it remained as they were.



C.&N.W.Ry. CHICAGO TERMINAL

SECTION OF TYPICAL ALLEY SUBWAY

0 1 2 3 4 5 6 9 12

Scale

FIG. 17.

The requirements of the design were:

1st. A waterproof structure over the team-way south of the freight house.

2nd. A waterproof and fireproof structure for the freight house.

3rd. A waterproof and smokeproof structure over the P. C. C. & St. L. Ry. tracks.

The above conditions together with the difficulty in arranging supports for the structure made the design very complex.

In Plate X is shown a general plan, longitudinal section and cross sections of the structure. There are seven lines of girders throughout the structure. Across the team-way two of these girders, on the east, span from the abutment to the south wall of the freight house. The other five lines of girders in this part of the structure are divided into two spans each by columns placed in the team-way. This line of columns is parallel with the abutment, making the five short girders of the same length. All the other girders in the entire structure are of different lengths. Columns are placed in each wall of the freight house under each line of girders. Another line of columns is placed in Carroll avenue north of the north main track of the P. C. C. & St. L. Ry. All lines of girders are straight and parallel from the south abutment to the north line of the freight house. From this line to the north abutment they are parallel with each other, but skewed to give equal clearance on both sides of cars passing around the curve.

The location of all columns was fixed by coördinates as explained under the head of Maps and Surveys. From these coördinates the lengths and direction of all girders were calculated.

All the foundations are of concrete supported on piles as shown in Plate XI. The columns in the team-way are supported on continuous foundations. It will be noticed that the foundation under the north wall of the freight house lies partly over the main track and by-pass of the Illinois Tunnel Co.'s tunnel under the freight house. The top of this tunnel is only 25 ft. 10½ in. below the bottom of the foundation. Piles 28 ft. long were driven in the foundation, and care was taken to drive them down as near to the tunnel as possible without striking it. Those driven alongside the tunnel were not driven lower than its top. No damage was done to the tunnel walls. There were a number of cases where foundations were constructed in streets directly over the tunnels, and our experience demonstrated that danger of damage to the same only occurred where piles were driven lower than the top and along the side of the tunnel, except, of course, where they struck the concrete lining. Even when piles were driven a considerable distance from the tunnel it was found there was danger of cracking the walls if many piles were driven together, on account of the crowding effect. In one instance some cracks resulted when piles were driven 25 ft. away.

The footings of the foundations in Carroll avenue extended some distance under the P. C. C. & St. L. Ry. north main-line track. The manner of constructing these foundations without interrupting traffic on the track is shown in the sketch of Section

A-A. The piles under the track were driven during the longest interval between trains, when the outside rail was temporarily removed.

Referring again to Plate X, it will be observed that the construction over the team-way, freight house and north half of Carroll avenue is the ordinary type of plate girders with I-beam floors. The I-beams are solidly embedded in concrete. There are no unusual features in this portion of the superstructure. Over the P. C. C. & St. L. Ry. tracks, however, the girders are of very unusual section and will be described in more detail.

These girders span from the north wall of the freight house to the columns in the center of Carroll avenue. They are all of different lengths varying from 100 ft. 4½ in. on the east to 84 ft. 7 9/16 in. on the west. The floor on this section, and over the entire structure is composed of 15 in. I-beams spaced approximately 18 in. center to center. Over the P. C. C. & St. L. Ry. tracks the I-beams and the bottom flanges of the girders are entirely enveloped in concrete, so there is no metal exposed below. This heavy mass of concrete with the rock-ballasted track produce an enormously heavy dead load. The dead load is made up as follows:

Track and ballast,	200	lb. per sq. ft. of floor.
Concrete,	210	" " " " " "
I-beams.	40	" " " " " "
Total:	450	

This is equivalent to 7,200 lb. per lineal foot of girder. The weight of the heaviest girder is 1,140 lb. per lineal foot, making the total dead load 8,340 lb. per lineal foot of girder.

The live load assumed was Cooper's E-50 loading. Eight-tenths of two full track loads was used for the intermediate girders.

Impact was calculated by the formula—

$$I = \frac{L^2}{L+D}$$

but as this structure was near the terminal yard, where the speed of trains would never be great, only one-half of this impact was used.

The girders are all 10 ft. deep, back to back of flange angles, but the sections all varied as the girders were of different lengths. The make-up of only the heaviest will be given, being the second from the east, and 96 ft.-6⅜ in. center to center of end bearings. The web is 119¾ in. by ¾ in. The top flange is composed of six 6 in. by 6 in. by ¾ in. angles, two 11 in. by ¾ in. side plates, one 16 in. by ⅞ in. and three 16 in. by ¾ in. cover plates. An elevation and section of this girder is shown in Plate XII. The distance from the back of the top angles of the top flange to the center of gravity of the flange is 4.6 in. and from the back of the bottom angles of the bottom flange to the center of gravity of this flange is 1.8 in. The effective depth is therefore 120 in. less (4.6 in. + 1.8 in) = 113.6 in.

The gross area of the top flange is 124.96 sq. in. and of the bottom flange 124.26 sq. in. The area of the web is 89.81 sq. in., making the total area of the cross section at the center of the girder 339.03 sq. in., or 2⅜ sq. ft. One-eighth of the area of the web was considered effective in the flange section.

Several different forms of girder sections were considered, and this one adopted because it presented a minimum of objectionable features. The principal objections which we sought to minimize were

(1) wide top flanges, and

(2) long rivet grips;

the former on account of the lateral clearance between girders and the latter on account of the uncertainty of the effectiveness of long rivets.

The maximum rivet grip through the four cover plates and top angles of the top flange is 4 in. Through the webs, except at the stiffeners it is 4 in., and at the stiffeners 4¾ in. While these grips are pretty long, they are within the limits of good conservative practice.

The girders are all fixed to the columns at the north end, and expand on nests of 9 in. segmental rollers at the south end. At the north end the girders are notched from the top to form a seat for the girders over Carroll avenue, while at the south end they are notched from below to make room for the cast shoes and roller nests which rest on the notched ends of the girders over the freight house, as shown in Plate X. Special care was taken to reinforce the re-entrant angle formed by the notch over the east shoe.

The method employed for erecting these girders was interesting. The track had been built from the north to Carroll avenue. The columns in Carroll avenue and the spans over the street were erected by a derrick car on the track. The spans over the freight house and team-way were hauled forward and erected by gin poles, and the freight house roof completed. One of the freight house tracks near the center of the long girder span was then abandoned for a few days and a wooden bent was erected at this point. Another wooden bent was erected just south of and close to the steel bent in Carroll avenue. The space between the wooden bents was spanned with 8 in. by 16 in. by 32 ft. stringers. A stiff-leg derrick was then set up on the roof of the freight house. A flat car carrying one girder at a time was run out on the wooden trestle, which brought the south end within reach of the stiff-leg derrick. The girder was lifted and set in place by the stiff-leg derrick at one end and a derrick car on the track over Carroll avenue at the other end. Two girders were set in place by this method and the floor beams between them put in, completing a track across the structure, after which the remaining girders were set with the derrick car.

The concrete construction and drainage plan of the floor is shown in Plate XII. As previously stated one of the requirements of the design was that the structure be made smoke proof from beneath. The I-beams of the floor and the lower flanges of the girders were therefore completely enveloped in concrete. The method adopted for insuring the adhesion of the concrete to the broad bottom flanges is clearly shown in the figure. Bent rods ½ in. in diameter were passed under the flange and anchored with hooked ends into the concrete above. These rods while helping to hold the enveloping concrete around the flange in place, also served as a support for a sheet of No. 16 gage 1½ in. mesh expanded metal which passed under the flange and was bent up over the edges of same. The expanded metal was kept about one in. from the bottom of the lower cover plate.

The concrete around the flanges was made of torpedo sand and Portland cement mixed very wet and thoroughly worked into place. After the flanges were covered, the concrete placed above was made from pit-run gravel which contained a considerable amount of large stone. The surface of the concrete was finished with a wooden float.

The span being on a grade of 0.65%, the water is drained to one end and carried into a metal down spout through a cast iron drain shown in the detail sketch. One of these drains is provided for each track. The floors are waterproofed in the manner previously explained.

Structure Over Kinzie and Clinton Streets.

The terminal tracks are carried over Kinzie and Clinton streets on a steel structure which is very complicated by reason of the Galena Division and Wisconsin Division surface tracks which unite at this point. A plan and sections of this structure are shown in Plate XIII. The two main-line tracks of the Galena Division and turn-outs leading to a team yard just west of Clinton street, cross under the structure just south of Kinzie street, while the two main-line tracks of the Wisconsin Division lie partly under the structure, approaching from the north. Immediately east of the Wisconsin Division tracks, and parallel to them are four freight house tracks which stop at the north line of Kinzie street.

Columns could only be placed in the curb lines and on the center lines of the streets (except at the intersection of the center lines of Kinzie and Clinton streets) and at proper clearance distance from the tracks. The structure is 96 ft. wide and carries six terminal tracks. The floor of the structure over all surface tracks is composed of I-beams or plate girders, the latter being used when the span was too great for the economical use of I-beams, and they are fully protected from gases from beneath by concrete. All portions of the floor not over surface tracks are trough sections.

The limitations on column locations made it impossible to locate columns in all cases at the most important bearing points. This is particularly noticeable between the Wisconsin Division main-line track and the first house track, where, for part of the distance, the floor beams are extended beyond the columns, forming cantilevers which carry the facia girders, and the balance of the distance the floor beams are extended beyond the facia girder bearings to the supporting columns.

An expansion joint is introduced along the girder in the south curb line of Kinzie street, which changes direction at the east end of this girder, extending across the Wisconsin Division tracks between two floor beams. The trough sections on one side of the girder are bolted to it through slotted holes. Diaphragms are placed in the troughs on either side of the girder, and six inches from the center of it, which make a continuous channel twelve in. wide, running the full length of the girder. This channel is filled with a soft, yielding, asphalt mastic, over the top of which the regular waterproofing is carried continuously. This detail is shown in Section L-L. In that part of the expansion joint over the Wisconsin Division tracks, shelf angles are riveted to the sides of two floor beams as shown in Section K-K which carry a heavy steel plate laid loosely upon them. This also forms a continuous channel which is treated the same way. The structure is also free to expand on the abutment at the south end and some movement may take place on the north abutment of Kinzie street.

The question of drainage was a serious problem. The surface of the concrete was sloped to drain to all abutments, where any water will find its way into tile drains placed along the back of the abutments and below the surface of the filling. These drains lead into manholes which communicate with the city sewers. Between the two abutments, however, was a considerable area which could not be drained in this way on account of the distance. It was not thought advisable to carry drains of ordinary size pipe down any of the street or curb line columns, on account of the danger of freezing. A point was therefore selected in the triangle east of Clinton street and south of Kinzie street where a 12 in. wrought iron pipe could be carried from the floor of the structure down to a manhole connecting with the city sewers. Dependence is placed on the warmth from the sewer to prevent freezing. A special drain casting, shown in the detail sketch, was designed with slotted openings to admit water but exclude the ballast, and set into the concrete of the floor. This method of drainage was employed at several other points on the approaches where conditions were similar.

Structure Over Team Yard East of Jefferson Street.

The triangle north of Kinzie street, east of Jefferson street and bounded on the east by the Wisconsin Division main-line tracks was originally utilized as a coach cleaning yard. The tracks were all on curves and connected at the south end with either the Wisconsin or Galena Division tracks in the vicinity of Kinzie and Clinton streets. The construction of the terminal elevated structure made it necessary to abandon these tracks as a coach yard. In order to utilize to the fullest extent this valuable space it was converted into a team yard. Eight tracks were laid parallel with Jefferson street, with stub ends at the north line of Kinzie street. The tracks were spaced 18 ft. and 35 ft. apart alternately. Concrete piers were erected between the tracks that were 18 ft. apart and at the east line of Jefferson street. The space between tracks 35 ft. apart was paved with brick for teamway purposes. A general plan of the structure is shown in Plate XIV.

In order to obtain sufficient clearance for cars, the piers were made only four feet wide with the sides vertical. Reinforcement was used in each face consisting of ¾ in. bars spaced 12 in. apart, set vertically. The footings were spread out to 10 ft. 6 in. in width and were supported on four rows of piles. The superstructure consists of plate girders spaced 6 ft. 2 in. apart and set normal to the center line of piers. The short girders on the sides frame into facia girders set parallel with chords of the curved terminal tracks. The floor consists of 8 in. I-beams, 12 in. apart set on top of and at right angles to the main girders. The entire floor is covered with concrete extending from the bottom of the I-beams to 1½ in. above the top of same at the ends of the girders and 4½ in. at the center of span—3 in. slope being provided for drainage.

The method of draining the surface of this structure deserves special comment. The water flows on the surface of the floor to the ends of the spans directly over the centers of the piers. There is a slot in the floor concerte on this line six inches wide; that is the concrete of one span is separated six inches from the concrete of the adjoining span. This slot is covered by a cast iron grating, made in sections, which holds the rock ballast, but permits the water to flow through. A channel is formed in the top of the pier, into which the water drops. This channel runs the entire length of the pier, except at the ends where the facia girders rest. A 12 in. wrought iron pipe is built in the center of the pier at each end, on a slope of about 45° leading from this channel to manholes located in the ground at the ends of the pier. The channel in the top of the pier is sloped to the upper ends of these pipes. A 12 in. sewer on each side of the structure connects the several manholes together and leads to the city sewer in Jefferson street.

Retaining Walls Along Wisconsin Division Tracks.

Under the head of Special Construction should be mentioned a unique type of retaining wall built along the Wisconsin Division tracks from May street to Wade street. These tracks were among the first to be elevated by this company in the city, the work having been done in 1898-9. But as the streets were all depressed and a maximum clear headroom of only 12.5 ft. was given, a further elevation was necessary to connect these tracks with the Terminal tracks, where 14 ft. headroom was given without depression.

The old retaining walls were built of rubble limestone on a natural cement concrete base. The face of the wall was vertical and on the right of way line. Outside of this line was private property. There was no projection of the concrete footing beyond the face of the wall. The base was too narrow to permit of raising the wall higher by additional masonry, and the natural cement concrete had disintegrated so badly in places as to be unfit for sustaining a greater pressure. Furthermore, to have excavated for a new base of a standard wall, of the proper width for the increased height, would have necessitated either the temporary removal of two tracks or the use of very heavy shoring to hold back the embankment. The former was objectionable, for the traffic was heavy at this point and it was desired to avoid increasing the congestion as much as possible. The latter was also objectionable on account of the cost that the work would involve and the danger that would attend any scheme for shoring in such a restricted space; for it must be remembered that shores could not be placed outside the right of way line. It was impracticable to rebuild the wall entirely of concrete unless the face was set back from the right of way line a distance equal to the thickness of the forms; for in many places houses were built snug up against the face of the old wall.

To meet these conditions a special type of wall was designed and constructed, shown in Fig. 18. One track was temporarily removed and the sand filling excavated as shown. The old wall was then removed entirely. The concrete footing under the toe of the wall was then put in place. The face of the new wall was built of stone from the Duck Creek quarries in Wisconsin. This is a dolomite limestone of a very good quality for heavy masonry if protected from the percolation of water. But like all limestones, will disintegrate more or less when used in damp places and subjected to freezing and thawing.

The face of the wall was laid with alternate headers and stretchers, while the backing was of concrete. No headers were allowed to be used with tapering points, and if a header was wider at one end than at the other, the narrow end was made the face. In that way the header was dovetailed into the concrete backing.

The heel of the wall was at a considerable distance above the toe, and the peculiar form shown in the figure was given to the

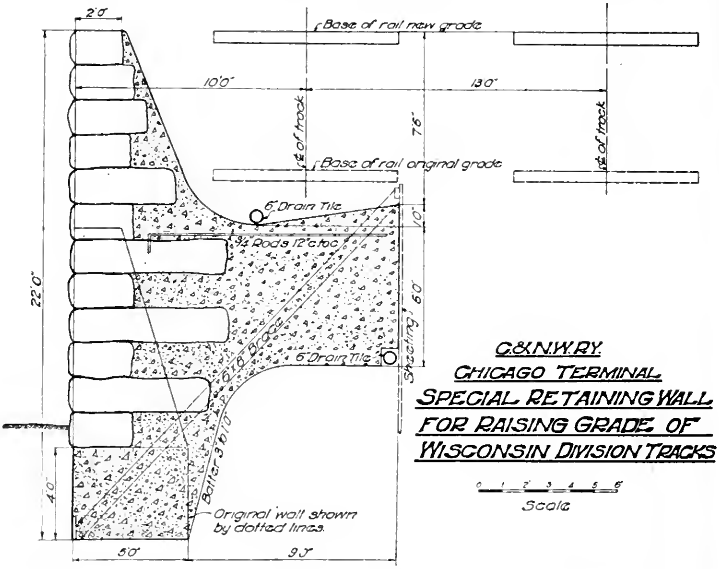


FIG. 18.

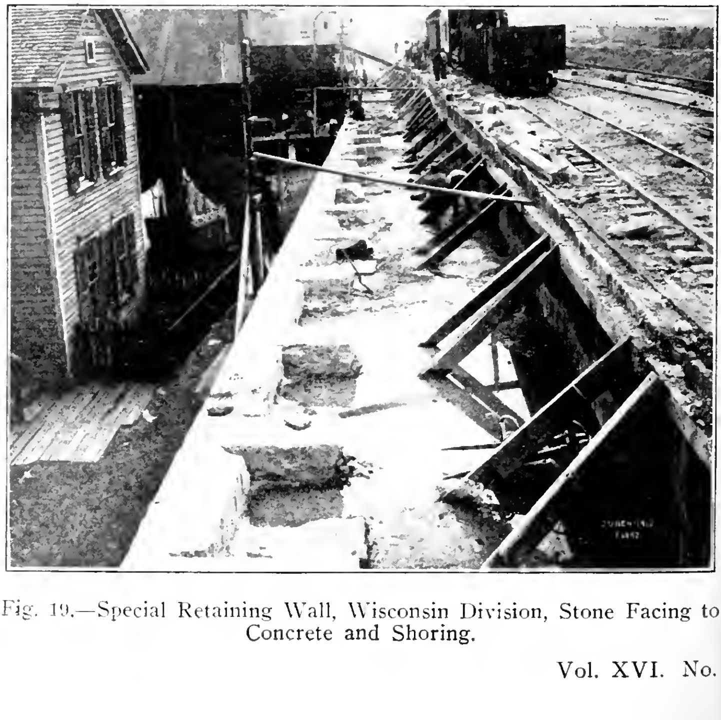


Fig. 19.—Special Retaining Wall, Wisconsin Division, Stone Facing to Concrete and Shoring.

rear portion. "Hammer Handle" is a nickname that has been applied to this construction, suggested by its peculiar shape.

The thickness of the tail was usually made about 5 ft. at the shallowest point, which was about 5 ft. from the rear end. The upper surface of the tail was given a concave finish to facilitate drainage. A 6 in. tile drain was laid in the trough thus formed which carries the water to manholes at the street lines connected with the city sewers. Six inch drains are also placed under the heel of the wall which connect with the same manholes.

In order to bind the tail more firmly to the body of the wall, and to prevent rupture through the tail, due to the downward pressure upon it and the outward pressure on the upper part of the wall, ¾ in. reinforcing bars spaced 12 in. apart were placed horizontally within about 6 in. of the upper face of the tail. These bars were bent down at one end and anchored into stone headers.

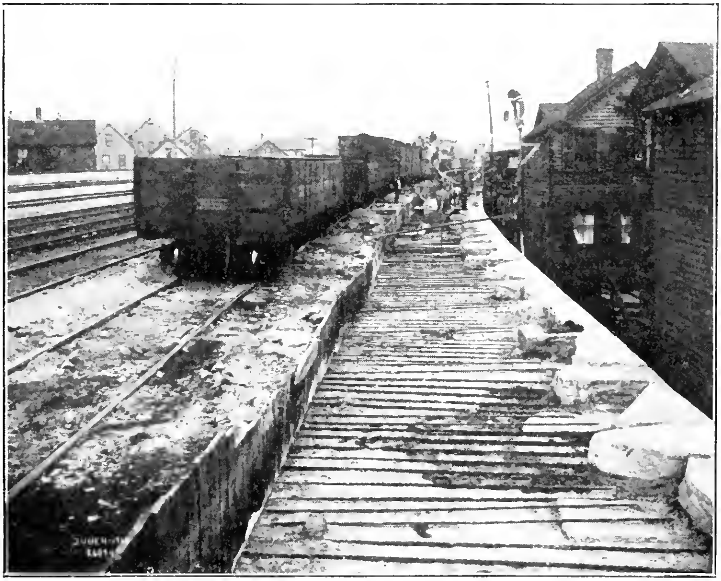


Fig. 20.—Special Retaining Wall, Wisconsin Division, Showing Reinforcing Bars.

Careful records have been kept since the completion of these walls and the resumption of traffic on the tracks over them, but no movement of any kind has been detected. Some of them have now been in use about 10 months.

It has occurred to the writer that there is one feature of this type of wall that might frequently be employed as a measure of economy. That is the saving in excavation and masonry effected by setting the foundation of the heel higher than the foundation of the toe. There are usually but two reasons for carrying the foundations of a retaining wall lower than the surface of the ground. The first is to reach a material that will sustain a greater pressure; and the second to get the foundation below the action of frost. The first is usually only necessary under the toe of the wall, for almost any good soil will sustain the heel pressure. The second also is only necessary under the toe for the heel is protected from frost by the embankment.

TRACK LAYOUTS.

Track layouts can only be intelligently presented in connection with the plan of operation. A diagram of the terminal tracks and their connections is shown in Fig. 21. It indicates by arrows the direction of train movements so far as they are fixed. Tracks on which direction of movement is not shown are switching or industry tracks and are used in either direction.

The long tracks at and just west of the center of the station yard are used principally for through trains on both divisions. The shorter tracks on the west side of the yard are used principally for Galena Division suburban trains; while the short tracks on the east side are used principally for Wisconsin Division suburban trains.

All coaches on through trains for both divisions and all suburban coaches on Galena Division trains are stored and cleaned in the California avenue coach yard on the Galena Division. All empty coach trains between the station yard and this coach yard pass outbound on track No. 3 and inbound on track No. 4 of the West Approach. All regular scheduled Galena Division trains pass outbound on track No. 1 and inbound on track No. 2.

All suburban coaches on the Wisconsin Division are stored and cleaned in the Erie street coach yard located east of the North Approach tracks. Empty coach trains between this coach yard and the station yard enter upon and depart from the terminal tracks principally through the Carpenter street interlocking plant where direct connection is made with tracks Nos. 3 and 4 of the North Approach. In case of a congestion at this point the transfer can be made further north through the Division street interlocking plant. Terminal track No. 4 is an empty coach train track, and the direction of movement on it is changed at midnight and noon and fixed in accordance with the heaviest movement, which is outbound in the morning and inbound in the afternoon. Track No. 3 alternates with No. 4 as an empty coach train track, being inbound in the morning and outbound in the afternoon for regular scheduled trains on the Evanston branch of this division. Track No. 2 is inbound for all Mayfair branch trains and inbound in the afternoon for Evanston branch trains. Track No. 1 is outbound for all Mayfair branch trains and outbound in the morning for Evanston branch trains.

Tracks Nos. 5 and 6 are the main running tracks into the Wells street station and the Erie street freight yard and connect through the Division street interlocking plant with the outbound and inbound tracks of the Mayfair and Evanston branches respectively, by means of properly arranged crossovers.

The system of switches at the junction of the two approaches and the system at the entrance to the station yard are controlled by separate interlocking plants referred to as the Clinton street and Lake street plants respectively. All trains leave the Station Yard through the Lake street interlocking plant unclassified as to routing except what initial classification can be given with respect to the two divisions. Complete classification as to routing is given to all Galena Division trains in the Clinton street interlocking plant, while the classification of all Wisconsin Division trains is complete

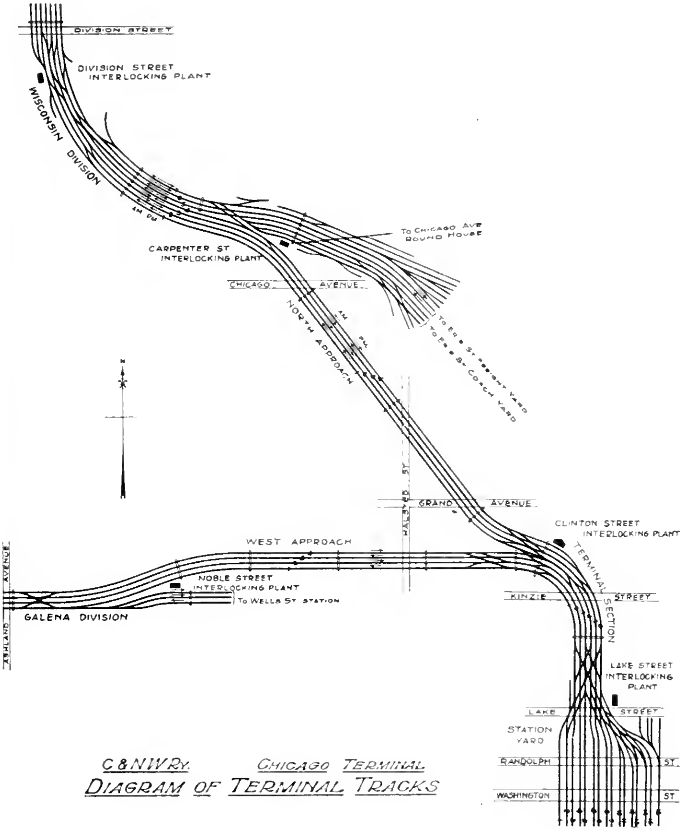


FIG. 21.

in this plant so far as it applies to the North Approach of the Terminal. Final classification, or the complete separation between Mayfair and Evanston branch trains, is made in the Division street plant.

The Wisconsin Division suburban trains constitute about 60% of all trains arriving at and departing from the New Terminal. Wisconsin Division through trains constitute about 10% of this traffic. Therefore about 70% of all trains arriving at and departing from the Terminal will pass over the North Approach. It will be observed that track No. 4 of the West Approach and track No. 1 of the North Approach unite in track No. 4 of the throat of the Station Yard which corresponds with track No. 6 in the station. This line divides the trackage in the station in about the same ratio as the traffic on the two approaches and makes an admirable arrangement, with the assignment of trackage in the station previously explained, for passing the traffic on the two approaches, into and out of the station with a minimum of crossover movements.

A very complete system of crossovers has been provided in the throat of the Station Yard. A double "scissors" ladder connects the six throat tracks In addition to these, double, triple and quadruple ladders connect the ends of the yard tracks, with double slip switches on all intersecting tracks, the object of the design being to provide for the greatest number of simultaneous movements into and out of the Station Yard.

A double system of crossovers with No. 10 frogs was introduced between the four tracks of the West Approach, east of Ashland avenue and a switch was placed in track No. 1 connecting with the surface tracks leading to the Wells Street station. One of these crossovers gives a direct connection between the non-scheduled tracks 3 and 4 and the Wells Street station surface tracks; the other makes direct connection between scheduled tracks 1 and 2 of the Galena Division and non-scheduled tracks 3 and 4 of the West Approach, and are principally for emergency purposes.

The frogs in the system of switches at the entrance to the terminal yard are No. 7. The limiting distances precluded the use of frogs of smaller angle. Outside of this system No. 10 and No. 14 frogs were used. All frogs are of manganese steel, either of the one-piece manganese steel casting type or of the built up type with manganese points and centers. All double slip switches have movable center points.

ORGANIZATION.

The construction operations were carried out under the general direction of Mr. J. M. Whitman, Vice President of Construction.

The construction organization, however, was under the immediate direction of Mr. Edward C. Carter, M.W.S.E., Chief Engineer, who was the active head of the construction department. All engineering questions were decided by him; all plans drawn subject to his approval and all construction work prosecuted in accordance with his directions.

Frost & Granger were the architects. Their work included the design and superintendence of construction of the station building, the enclosing walls of the station yard, all rooms underneath the track floor, the power plant and signal towers. They also superintended the construction of the concrete, waterproofing and glazing of the train shed roof, although the design of the roof was made under the writer's supervision in connection with the steel frame work of the train shed.

E. C. & R. M. Shankland, MEMS.W.S.E., were the Consulting Structural Engineers for the architects. They designed the steel work and foundation for the station building and power house, including the chimney and its foundations.

Pierce, Richardson & Neiler were the Consulting Mechanical and Electrical Engineers for the architects. They designed and superintended the construction of the heating, ventilating and electrical equipment.

Mr. W. H. Finley, M.W.S.E., Assistant Chief Engineer, was freely consulted on various engineering problems. His long experience in structural work rendered his advice of great value.

The writer was Terminal Engineer in charge of the preparation of all plans and the execution of all work pertaining to the track and track structures, train shed, viaducts, retaining walls and foundations, with general supervision over all construction work, reporting to the Chief Engineer.

Mr. W. L. Curtis was Assistant Terminal Engineer in charge of the field work of construction.

Mr. J. C. Sanderson, M.W.S.E., was Structural Engineer in charge of all work on plans prepared in the office of the Terminal Engineer.

Mr. F. W. Hillman, M.W.S.E., was Assistant Engineer on the Terminal Section and Station Yard.

Mr. W. R. Kettenring was Assistant Engineer on the West Approach and Mr. F. N. Graham, Assistant Engineer on the North Approach.

Mr. J. A. Peabody, the company's Signal Engineer, prepared all plans for the signal and interlocking plants and superintended the construction of same.

Mr. R. M. Phinney was assistant engineer in charge of signals and interlocking.

Mr. A. J. Farrelly, Electrical Engineer for the Telegraph Department, supervised all electrical installation over which his department has control.

CONCLUSION.

This brief account of the Terminal Improvement would be very incomplete if it did not specifically name the controlling mind that conceived and directed the entire project. I refer to Mr. Marvin Hughitt who for 24 years was President of the Chicago & Northwestern Railroad Company and is now Chairman of the Board of Directors. To the wisdom and foresight which he brought to bear on the many questions involved is due the success of the accomplished fact. Every feature of the plans, whether relating to architectural treatment, economy of construction and operation, or the comfort and convenience of patrons was analyzed and carefully studied by him. A great deal of his personal attention was given to the minor details. The diligence, zeal and tireless energy with which he pursued every phase of the work was an inspiration to those upon whom the execution of the work devolved.

Special mention should be made of the very valuable assistance and advice in the preparation of plans pertaining to the general arrangement and the economies of operation given by Mr. W. A. Gardner, who through the greater portion of construction period was Vice President in charge of operation, and is now President of the company. For such advice he was eminently qualified by his long experience as an operating officer.

A full measure of credit should also be accorded to the work of the late Lloyd W. Bowers, General Counsel, for that degree of fairness and foresight in the drafting of the various ordinances and for that honest straightforward and business like method in which all negotiations with the city council and public boards were conducted.

To that spirit of fairness is due the friendly feeling and hearty co-operation accorded by all departments of the city government. And the writer wishes to take this opportunity on behalf of all those upon whom responsibility for the work was placed, to express the appreciation felt by one and all for that spirit of equal fairness manifested by all the city executive departments, and the friendly co-operation which prevailed throughout the entire work.

APPENDIX.

AREAS, DIMENSIONS, ETC.

Area of station building, 320 ft. x 218 ft.	69,760 sq. ft.
Area of station yard, 320 ft. x 1,072 ft.	343,040 sq. ft.
Area of train shed roof	265,800 sq. ft.
Area of right of way acquired	37 acres.
Area of right of way covered with buildings	20 acres.
Buildings wrecked or moved (4 stories and over)	66
Buildings wrecked or moved	455
Number of tracks in station yard	16
Total length of yard tracks	14,330 ft.
Capacity of yard tracks	200 cars.
Length of shortest yard track 623 ft., capacity	8 cars.

Length of longest yard track 1,147 ft., capacity	17 cars.
Number of tracks in station approach	6
Number of passenger platforms	8
Width of platforms	16 ft., 9 in.
Aggregate length of platforms	7,160 ft.
Number of streets bridged	40
Number of alleys bridged	13

AREAS OF ROOMS IN STATION BUILDING.

First Floor—Street Level.	
Ticket office	4,890 sq. ft.
Lunch room	4,600 sq. ft.
Serving room	400 sq. ft.
Drug store	1,900 sq. ft.
Station master's office	350 sq. ft.
Telephone booths	600 sq. ft.
Telegraph offices	350 sq. ft.
Parcel check room	1,350 sq. ft.
Baggage check room	4,500 sq. ft.
Baggage room	18,500 sq. ft.
Baggage master's office	1,170 sq. ft.
General baggage agent's office	450 sq. ft.
Baggage clerks' room	1,650 sq. ft.
Baggage stock room	600 sq. ft.
Baggage driveway	11,300 sq. ft.
Carriage concourse (public)	8,600 sq. ft.
Carriage concourse (private)	2,650 sq. ft.
Public space	21,900 sq. ft.
Second Floor—Track Level.	
Main waiting room	25,000 sq. ft.
Dining room	4,000 sq. ft.
Serving room	425 sq. ft.
Women's room	2,900 sq. ft.
Women's toilet	1,300 sq. ft.
Men's toilet	1,450 sq. ft.
Men's pay toilet	400 sq. ft.
Smoking room	1,200 sq. ft.
Barber shop	600 sq. ft.
News stand and check room	1,000 sq. ft.
Telephone lobby	350 sq. ft.
Concourse	17,000 sq. ft.
Third Floor.	
Division superintendent's offices	850 sq. ft.
Assistant superintendent's offices	450 sq. ft.
Train dispatcher's office	1,800 sq. ft.
Division engineer's offices	3,450 sq. ft.
Clerks' offices	3,400 sq. ft.
Filing rooms	1,275 sq. ft.
Chart room	500 sq. ft.
Blue print room	225 sq. ft.
Men's toilet room	550 sq. ft.
Women's retiring room	1,200 sq. ft.
Women's lavatory	750 sq. ft.
Women's toilet	550 sq. ft.
Tea room	1,250 sq. ft.
Serving room	150 sq. ft.
Emergency rooms	2,100 sq. ft.
Matron's room	225 sq. ft.

Barber shop	725 sq. ft.
Bath and toilet rooms	2,000 sq. ft.
Men's writing room	700 sq. ft.
Fourth Floor.	
Conductors' rooms	1,600 sq. ft.
Conductors' locker room	1,150 sq. ft.
Telephone exchange	300 sq. ft.
Electrical engineer's office	450 sq. ft.
Electrical engineer's laboratory	500 sq. ft.
Electrical engineer's clerk and file room	525 sq. ft.
Pullman company's office	1,350 sq. ft.
Time inspector.	275 sq. ft.
Men's toilet	450 sq. ft.
Women's toilet	450 sq. ft.
Unfinished space	13,000 sq. ft.
Basement.	
Kitchen	3,800 sq. ft.
Butcher shop	600 sq. ft.
Refrigerator room	1,200 sq. ft.
Store rooms	2,400 sq. ft.
Women employes' locker rooms	800 sq. ft.
Women employes' toilet room	375 sq. ft.
Women employes' rest room	975 sq. ft.
Baggage employes' locker room	1,420 sq. ft.
Station employes' locker room	800 sq. ft.
Public toilet	2,700 sq. ft.
Baggage store room	24,000 sq. ft.
Baggage record room	2,650 sq. ft.
Boiler room	3,000 sq. ft.
Fan room	300 sq. ft.
Switchboard room	500 sq. ft.
Engineer's office	350 sq. ft.
General space	18,000 sq. ft.
Brakemen's locker room	2,500 sq. ft.
Brakemen's room	1,900 sq. ft.
Coal storage	650 sq. ft.
Rooms Between Washington Boulevard and Randolph Street —Street Level.	
United States post office sub-station	24,470 sq. ft.
Mail distributing platform	4,300 sq. ft.
Mail wagon driveway	8,800 sq. ft.
Mail employes' lounging room	1,130 sq. ft.
Men's toilet	750 sq. ft.
Suburban concourse	15,300 sq. ft.
Cab and automobile stand	19,850 sq. ft.
Emigrants' quarters.	
Waiting room	10,300 sq. ft.
Women's toilet	1,140 sq. ft.
Women's bath	475 sq. ft.
Men's toilet	950 sq. ft.
Lunch room	830 sq. ft.
Kitchen	590 sq. ft.
Unassigned space	29,150 sq. ft.
Rooms Between Randolph Street and Lake Street —Street Level.	
Trucking space	11,650 sq. ft.
Out-going baggage room	16,400 sq. ft.

Out-going baggage clerks' room	1,750 sq. ft.
Railway mail room	550 sq. ft.
Express room	10,350 sq. ft.
Express offices	400 sq. ft.
Conductors' train box and locker room	1,700 sq. ft.
Lamp room	570 sq. ft.
Out-going mail room	6,000 sq. ft.
Transfer clerk's room	625 sq. ft.
Supply room	425 sq. ft.
Mail employes' lounging room	1,080 sq. ft.
Toilet rooms	710 sq. ft.
Express, baggage and mail driveway	28,000 sq. ft.
Registered mail post office	1,750 sq. ft.
Receiving and dispatching clerks' room	525 sq. ft.
Pipe room	3,200 sq. ft.
Unassigned space	21,500 sq. ft.
Fan room	690 sq. ft.
Baggagemen's locker and wash room	275 sq. ft.
Electrical supply room	900 sq. ft.
Dunn news service room	900 sq. ft.

Power House (North of Lake Street).

Boiler room	7,400 sq. ft.
Pump room	7,850 sq. ft.
Machine room	5,500 sq. ft.
Engine room	3,800 sq. ft.
Vestibule.	130 sq. ft.
Engineer's office	245 sq. ft.
Engine room gallery	160 lin. ft.

QUANTITIES OF WORK.

Excavation.	250,000 cu. yds.
Piles driven, 43,000	1,530,000 lin. ft.
Concrete.	265,000 cu. yds.
Structural steel in station and street viaducts	37,240 tons.
Waterproofing.	665,000 sq. ft.

Tracks.

North approach	33,500 ft.
West approach	26,700 ft.
Terminal section	34,500 ft.
Total, 94,700 ft.	18 miles.

Single switches	82
Lap switches	4
Double slip switches	39
Crossings.	6
Curbing.	22,400 lin. ft.
Cement sidewalk	266,300 sq. ft.
Paving.	51,250 sq.yds.
Caissons under station building	172
Caissons under walls of Washington street tunnel	36
Caissons under Lake street span	4
Caissons under chimney	4

Ninety-three of the caissons under the station building and those under chimney extend to rock, approximately 120 ft. below street level. All other caissons are founded on hard pan, approximately 85 ft. below street level.

Crushed stone ballast	70,000 cu. yds.

December, 1911

Electric conduits.	
Total lineal feet	**27,320 lin. ft.**
Total duct feet	**251,760 duct ft.**
Total manholes	**182**
Sewers.	
Total 1 ft., 2 ft., 3 ft. and 4 ft.	**7,610 lin. ft.**
Total new manholes	**47**
Fencing.	
Pipe railing on steel girders	**8,323 lin. ft.**
Pipe railing on retaining walls	**7,898 lin. ft.**
Picket fence.	**2,518 lin. ft.**
Total.	**18,648 lin.ft.**

PUBLICATIONS.

A number of articles have been published in the technical journals from time to time, describing certain features of the work. These articles in most cases have been prepared by the staff correspondents of the respective journals, and while they are generally correct, their accuracy in detail is not vouched for. The following are some of the most important articles:—

The American Architect:
  November 25, 1908, page 169.
Engineering Record:
  August 15, 1908, page 177.
  May 8, 1909, page 595.
  August 28, 1909, page 242.
  September 4, 1909, page 271.
  June 18, 1910, page 774.
Railway Age Gazette:
  August 14, 1908, page 711.
  July 16, 1909, page 105.
  March 18, 1910, page 737.
  July 15, 1910, page 128.
  March 23, 1911, page 663.
  June 9, 1911, page 1311.
Engineering News:
  October 18, 1906, page 412.
  October 29, 1908, page 471.
  August 17, 1911, page 191.
Railway and Engineering Review:
  August 15, 1908, page 660.
  June 10, 1911, page 510.
Electrical Review and Western Electrician:
  August 19, 1911, page 359.
Electrical World:
  August 19, 1911, page 435.
  August 26, 1911, page 483.
Power:
  April 4, 1911, page 514

DISCUSSION.

W. H. Finley, M. W. S. E. (Chairman): In announcing that the paper is open for discussion, I will say that no one can read Mr. Armstrong's description of this work without being impressed with the very difficult engineering problems that were met with;

and the masterly way in which they were carried out reflects great credit upon Mr. Armstrong and his able corps of assistants.

The plans and description of the work show the immense amount of preliminary study and detail work necessary in carrying it out.

W. E. Symons, M. W. S. E.: I do not see where anything can be added to Mr. Armstrong's paper, from an engineering standpoint, and his analysis is so thorough and complete that I fail to see any room for criticism. A thought or two, however, has come to me with respect to the subject matter of the paper, and its operation.

The railway companies of the United States have quite recently been subjected to numerous attacks from various sources, principally from politicians, magazine, and "yellow journal" writers, whose statements have, as a rule, been of a character that will not bear analysis.

Among other things the railways are charged with conducting their affairs in a slipshod, inefficient, and unbusinesslike manner; that nothing is reduced to a standard or systematic working basis; that a sort of "Rule of Thumb" method prevails which encourages inefficiency and invites dishonesty; and that in the matter of terminal facilities we have made little or no progress from conditions that obtained in the dark ages when transportation was effected through the medium of beasts of burden or on the *backs* of *human beings.* While many of these unwarranted and libelous attacks are not entitled to the dignity of consideration, yet it seemed to me not inappropriate to suggest that Mr. Armstrong's very able presentation of this proposition, covering as it does, in detail, every step from its first conception to the completed terminal, may be considered the last word in answer to statements calculated to poison the public mind against corporate interests.

I think I am right in saying that the New North-Western Terminal is one among three of the most beautiful in America, and with the possible exception of a bill of materials, the paper we have listened to this evening may be considered a text-book on the subject, and in that respect is of much value to the engineering world.

OPERATING FEATURES.

There is another feature pertaining to the operating capacity of the terminal that has occurred to me as one that would be of interest to both railway officers and engineers, in a study of this terminal, or consideration of proposed new ones. That is, the number of trains and passengers handled per day, subdivided as between the *rush* and *slack* periods, with some comparison as between maximum capacity, and probable maximum volume of business that may be anticipated.

In collecting some data on the item of number of commuters handled by the most prominent roads in the United States, recently I received the following figures based on the month of April, 1908:

Average number of commuters per day...... 606,554
Average number of commuters per year.....188,359,788

The number of trains and passengers handled by the four principal lines running into Chicago were as follows:

(BASED ON APRIL, 1908.)

ROADS.	Av. No. Trains per day	Av. No. Trains per hr. 12 hr. day	Av. Time B't'w'n Trains on 12 hr. basis	Average Number Passengers handled	
				Per Day	Per Year 309 days
C. & N. W. Ry...	227	19.15	3.15 min.	34,150	10,542,350
C., B. & Q. R. R..	64	5.3	11.3 min.	10,552	3,260,568
C., R. I. & P. Ry..	79	6.6	9.9 min.	14,295	4,417,155
Ill. Cent. R. R...	240	20.	3. min.	38,837	12,000,633
Total	610	51.05	....	97,834	30,220,706

In the foregoing calculations, the suburban or commuter business has been equally divided on a twelve-hour basis, while as a matter of fact there are rush periods both in the morning and evening, when the number of trains are far in excess of an average over the entire period. Add to this all the *regular* through, *special*, *excursion* and other train movements; then make a liberal allowance for the time trains stand in the depot to receive or discharge passengers, and the three-minute interval would doubtless be materially reduced.

In fact, I think it would be interesting to know just what periods of time now elapse between trains, under both normal and maximum conditions, at the throat or entrance tracks, and about what percentage of increased volume of business it is estimated can be handled.

My suggestion does not find support in any thought of criticism of the paper of the evening, but is offered for the author's consideration as an addition to his closure, with a view of anticipating such questions as will doubtless arise with operating officers when reading this highly interesting and valuable monograph.

Albert Reichmann, M. W. S. E.: The only thing I wish to say is that the American Bridge Company furnished the steel for practically all of this work and Mr. Armstrong's plans were a good deal like his paper—very comprehensive. Considering the complicated nature and magnitude of this work I have never seen its equal, from a structural standpoint, for the rapid progress made and the few difficulties encountered. I have every reason to believe that the balance of the work went along with the same degree of efficiency. Mr. Armstrong is to be very highly complimented upon the manner in which he has handled this entire problem.

L. K. Sherman, M. W. S. E.: I do not want to digress from the subject of railway terminals here, and I am not prepared to discuss that subject; but I will refer to one point mentioned in the paper in regard to the lowering of the water over the Washington street tunnel. I think that the amount of lowering is stated as 15 in. Owing to the normal fluctuations of Lake Michigan, no lowering of water surface due to the operation of the Chicago Drainage Canal can be detected by gauge readings. Calculations based on the government records show that any lowering of the Chicago River at Washington street, due to Drainage Canal flow, is less than 7 in.

C. R. Dart, M. W. S. E.: I would like to inquire regarding approaches, whether it was found more economical to use filled areas with retaining walls than a continuous steel structure, or whether it was because of the more stable character of the work with less maintenance that you used the filling.

Mr. Armstrong: It was found cheaper in all cases to build retaining walls and fill than it was to build steel structures. Not only the maintenance, but the first cost was considerably less. We made several comparative estimates. I do not remember the exact ratio now but it was so much in favor of the filling and retaining wall that steel structures were not considered except where needed.

Mr. Reichmann: Piles were used extensively in the retaining walls, I notice. Were concrete piles or ordinary timber piles used?

Mr. Armstrong: Ordinary timber piles were used.

Mr. Reichmann: Were the tops of the piles at or below the water-level of the river?

Mr. Armstrong: The piles were not down below the water line of the river, but they were down into the moist clay to be found under the city in all cases. We felt no hesitancy in putting in piles and allowing them to project above the water line, because in nearly all cases where we excavated down to the bottom of our foundations which were about six feet below the level of the ground, we almost invariably got into water.

Mr. Reichmann: About how much above lake level were the tops of those piles?

Mr. Armstrong: Generally about six to eight feet above the lake level.

Mr. Finley: I think all those piles are below the moisture line and also that the piles are entirely safe below the moisture line. It would not be necessary to have them below any established water line.

A. Bement, M. W. S. E.: This excellent and elaborate paper on the latest type of railway station has interested me very much, although the subject is somewhat familiar, because I have watched the erection of the terminal in passing from and to my office on the elevated railway. There are, however, a few questions I should like to ask.

It has been stated that when air was used in the caissons, when the excavation got into the sand and boulders, overlying the rocks, that air leakage was so great as to result in its finding exit by way of other "caissons," or open foundation wells, some distance away where other foundation work was in progress. This is a matter of serious importance, and it might be well to have more information along that line.

I would ask what the distance is from the river to Kinzie street along Wells street at the old station; also the measurement from Wells street to the North Branch of the river.

Referring to the new station, I would ask the width and length from Madison to Lake streets.

Regarding the snow melter, I would ask if it has proven entirely successful, and how many pounds of steam are required to melt a cubic foot of snow?

Why was no connection made with the Clinton street station of the Chicago and Oak Park elevated road, so that passengers could enter and leave without going to the ground? Also why was the elevated railway station moved from Canal to Clinton streets?

J. R. Calhoun: Mr. Armstrong has no doubt received so much praise from engineers who are really capable of analyzing his work that the applause of mere students sounds idle to him. However, when his paper is considered as a text-book, we younger men are perhaps qualified to add some slight measure of thanks for a clear and thoroughly understandable description of a masterly work.

There is one point, however, which Mr. Armstrong has not touched on in his paper and which to my mind might cause some possible trouble at a future date. That is the question of provision for conductors—namely, trolley wire or third rail, in the event of the ultimate electrification of the Terminal. The construction of the smoke ducts over the center of the tracks would seem to eliminate the possibility of the overhead trolley, and it would hardly seem advisable to install a third rail system in a station which handles such an enormous amount of traffic.

CLOSURE.

The Author: In complying with Mr. Symons' request that some information be given regarding the increased capacity of the new station over the old, I can only mention certain features which are factors in this increase. The ratio of increase cannot be expressed with any degree of reliability, as it depends upon the values assigned to these various factors, which must remain largely matters of individual judgment, or, more correctly, guesswork, until tried out in practice.

These factors are:

First, elimination of interruptions due to the bridge over the river in the throat of the Wells Street station yard, and the grade crossing of the C. M. & St. P. Ry. in Canal Street.

Second, increase in number of tracks in throat of yard from two to six.

Third, decrease in number of cross-over movements in throat of yard blocking parallel simultaneous movements. The old Wells Street terminal yard was divided into two parts, viz., the main station yard and the annex yard. All through trains and a part of the suburban trains arrived at and departed from the main station yard; while the balance of the suburban trains arrived at and departed from the annex yard. Any movement from the Wisconsin Division tracks into the annex yard, or from the Galena Division tracks into the main station yard, blocked a simultaneous movement on the two tracks in the throat. In paragraph seven, under the head of "Track Layouts," it is explained how these cross-over movements are largely eliminated in the New Terminal.

Fourth, increase of 70% in the standing capacity of the tracks in the New Terminal over the old; making it possible to accommodate longer trains or stand more trains on one track. The average number of cars in which passengers are carried is now 5.3 per train. The capacity of the shortest yard track is 8 cars and the longest track 17 cars. Therefore, so far as the track space is concerned, a considerable increase in the average length of trains is possible.

Fifth, increased capacity in throat of yard due to a more complete system of multiple ladder tracks, and an improved signal and interlocking system.

In reply to Mr. Symons' question regarding the number of trains and the interval between trains, I will state that there are now 324 regular scheduled trains per day arriving at and departing from the Terminal station. Of this number 252 arrive and depart in the twelve-hour period between 6:30 A. M. and 6:30 P. M., making an average interval of 2 min. 52 sec., which is equivalent to one train on each of the sixteen tracks every 45 min. 52 sec. But the average interval over a period of twelve hours is not the proper basis upon which to estimate the capacity of a station. The rush period is the crucial test. The busiest hour of the day is from 7:30 to 8:30 A. M., when 42 trains arrive and depart, making an average interval of 1 min. 26 sec. This is equivalent to one train on each of the sixteen tracks every 22 min. 56 sec.

Referring to the questions raised by Mr. Bement: Regarding the air from foundation caissons under pressure, bubbling up around adjacent completed or partially completed caissons, I will state that this is quite a common occurrence in pneumatic work. In sinking caissons in river beds I have frequently seen the air bubble up, not only around the caisson, but sometimes at distances of several hundred feet away. Whenever the cutting edge strikes a stratum of porous material, sand or gravel, the water in the stratum will be displaced by air horizontally from the cutting edge, providing there is a vent any place in the overlying stratum through which it can be forced. I do not think there is anything serious in this. The material is not displaced, but only the water which it contains.

In answer to the questions regarding the dimensions of the old Wells Street station yard and the new station yard, I will state that from the river to Kinzie Street, measured along Wells Street, is 425 ft., and from Wells Street to the river measured along Kinzie Street is 1,260 ft. The new station yard, measured from Canal Street to Clinton Street, is 320 ft., and measured from Madison Street to Lake Street is 1,324 ft.

Regarding the snow melters, we have not yet had an opportunity to test them practically, and no measurements have been made on the amount of steam required to melt a cubic foot of snow. In experimenting with them last winter, we found we could melt a full pan of snow in 30 seconds. The pan holds 21 cu. ft.

Referring to the question as to why no connection was made between the Clinton Street station of the Chicago and Oak Park Elevated Railroad and the New Terminal station, I will call attention to the fact that the New Terminal is on Madison Street, while the Clinton Street station of the Oak Park road is on Lake Street. *three blocks away.*

As to why the elevated station was moved from Canal to Clinton Street, I think the Oak Park Co. could answer this better. One good reason I can see for the change is that all trains approaching the river now stop on an up-grade, while they would have stopped on a down-grade had the station remained at Canal Street. This is due to the raise of grade we made in their tracks. The span over the throat of the Terminal yard is at the apex of the grades. There were probably other considerations that led to the change. Personally I think the change was a good one.

SIGNALING AND INTERLOCKING.

J. A. PEABODY.*

Presented September 20, 1911.

After the general lay-out for the New Passenger Terminal of the Chicago & North Western Railway Company had been decided on, the plans for the signaling and interlocking were immediately started.

OPERATION OF TRACKS.

By reference to the last figure of Mr. Armstrong's paper (Fig. 21), it will be seen that there are sixteen tracks in the depot, terminating in a six-track throat which in turn divides into two approaches—one from the north and one from the west, each approach having four tracks.

The north approach extends to a junction with the two divisions, the Wisconsin and Milwaukee, near Division street, each of these divisions having two main tracks. The west approach extends to a junction with the Galena Division near Noble street, this division having four main tracks.

A close study of the approaches and operation of the tracks where they joined the old track divisions, very quickly developed the facts that there were quite different conditions to be met.

All through empty coach trains for the divisions entering Chicago as well as the Galena Division suburban empty coach trains and all Galena Division scheduled trains were to be operated over the west approach, the coach yards being on the north side of the main tracks, the suburban business not very heavy, and the business as a whole scattered throughout the twenty-four hours.

The Chicago & North Western Railway is a left-hand operated road, with the result that it was found best to operate the four tracks as follows:

Track No. 1 (south track). West bound schedule trains.

Track No. 2 (next track north). East bound scheduled trains.

Track No. 3 (second track north). West bound empty coach trains.

Track No. 4 (north track). East bound empty coach trains.

As before stated, the conditions to the north were quite different. The two divisions have each two main tracks. These are parallel, and therefore form one four-track railroad operated as follows:

Track No. 1 (west track). North bound Wisconsin Division.

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*Signal Engineer, C. & N. W. Ry. Co.

Track No. 2 (next track east). South bound Wisconsin Division.

Track No. 3 (second track east). North bound Milwaukee Division.

Track No. 4 (east track). South bound Milwaukee Division.

In this direction there is a very heavy suburban business as well as a heavy through traffic, and the empty coaches for the suburban trains are kept in a yard which can be seen in Fig. 21, this coach yard being to the east of the north approach and not connected to it but must be reached from the tracks leading to the old depot.

Briefly, the studies resulted in the introduction of a cut-off or connection between the old line and the north approach just north of Sangamon street, to facilitate the operation of the coach movement and to prevent the heavy empty coach train movement coming from or going to the depot mornings and evenings crossing through the suburban and through scheduled trains at Division Street.

The following method of operating trains on the north approach was adopted:

Twelve o'clock midnight to twelve o'clock noon:

Track No. 1 (west track). All north bound scheduled trains.

Track No. 2 (next track east). South bound Wisconsin Division trains.

Track No. 3 (second track east). South bound Milwaukee Division trains.

Track No. 4 (east track). Empty coach trains for yard.

Twelve o'clock noon to twelve o'clock midnight:

Track No. 1 (west track). North bound Wisconsin Division trains.

Track No. 2 (next track east). All south bound scheduled trains.

Track No. 3 (second track east). North bound Milwaukee Division trains.

Track No. 4 (east track). Empty coach trains for depot.

During the morning hours such empty coach trains as there are for the depot go in on Track 3, and in the evening empty coach trains use this track with the scheduled trains outbound.

During the comparatively light traffic times, the Milwaukee Division scheduled trains are sometimes run in the direction of traffic on Track 4 to prevent interference with the Wisconsin Division trains.

This scheme has proven its practicability, and it will be readily seen that it provides a place always free to receive empty coach trains directly from the depot in the morning, and one for an inexhaustible supply of them for the depot in the evening.

Within the limits of the Division Street interlocking plant, trains are received from or sent to the tracks north in the direction of traffic in which the tracks have heretofore been used.

INTERLOCKING PLANTS.

Owing to the extent of territory covered by the switches in the depot-yard and for the junction of the north and west approaches, two interlocking plants were installed and provision was made for operating all tracks in both directions between them. However, the normal operation of the six tracks is as follows:

Tracks 1 and 2, numbering from the west: All trains for the west approach.

Tracks 3, 4, 5, and 6: The same as Tracks 1, 2, 3, and 4 on the north approach.

There are altogether five plants as follows:

Lake Street, Plate XV-A, including all the switches in the terminal yard.

Clinton Street, Plate XV-B, including all the switches at the junction of the north and west approaches.

Noble Street, Plate XVI-C, at the junction of the west approach with the Galena Division.

Division Street, Plate XVI-D, at the junction of the north approach with the Wisconsin and Milwaukee Divisions, and Carpenter Street, Plate XVI-E, to control the movements across the short cut-off between the north approach and the old Milwaukee and Wisconsin Division tracks.

The train movements on the north and west approaches and through the interlocking plants, except Lake Street, are protected by automatic block signals or by the automatic control of the interlocking signals. No automatic or block protection is provided in the Lake Street plant.

The illustrations show clearly the track lay-outs and the derail protection and signaling provided for each of the five interlocking plants and the diagram of the terminal tracks, Fig. 21, shows the location of the plants with relation to the depot and each other, and also the number and location of the signal bridges for automatic signals on the north and west approaches.

Attention is called to the apparent duplication of derails on some tracks within the Clinton Street plant, Plate XV-B. The derails farthest from the fouling point were installed to comply with the rules of the Illinois Railroad Commission requiring 500 ft. of protection on main tracks for facing moves, while those nearer the fouling point were installed to protect against trailing moves. Their introduction allows conflicting routes to be set up as soon as trains pass these derails, which are located at clearance points, instead of having to wait until the trains pass the derails farther away. It will readily be seen that this saves a great deal of time.

The signals and interlocking plants were furnished and installed by the General Railway Signal Company and we wish to give credit to them in large measure and especially to their engineer, Mr.

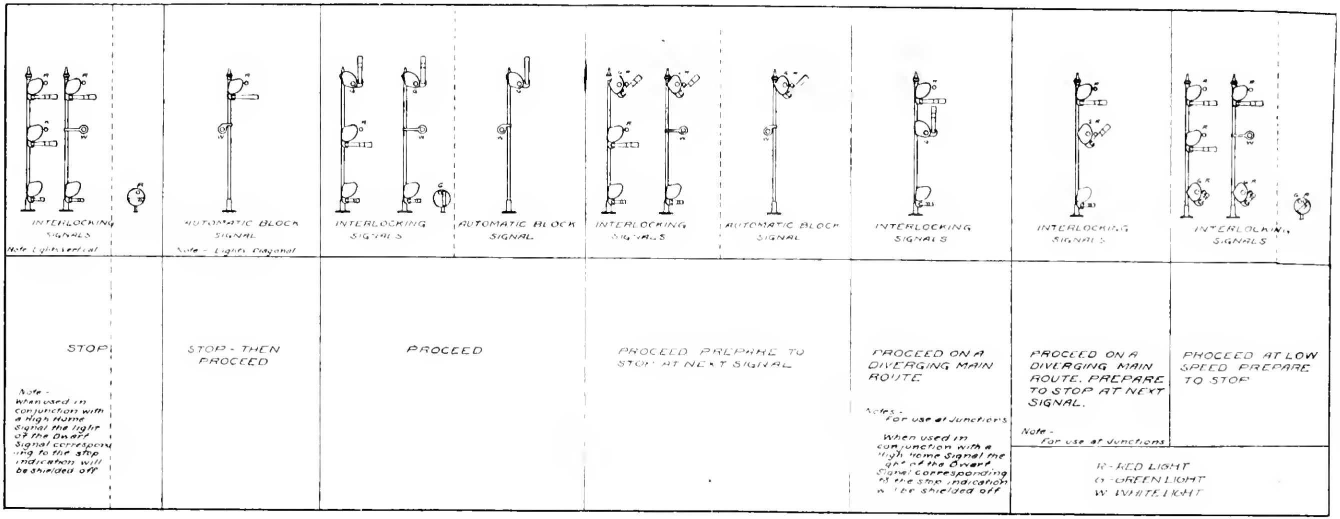

INTERLOCKING SIGNALS
Note Lights vertical
R
W
STOP
Note - When used in conjunction with a High Home Signal the light of the Dwarf Signal corresponding to the stop indication will be shielded off
AUTOMATIC BLOCK SIGNAL
Note - Lights Diagonal
STOP - THEN PROCEED
INTERLOCKING SIGNALS
G
AUTOMATIC BLOCK SIGNAL
PROCEED
INTERLOCKING SIGNALS
AUTOMATIC BLOCK SIGNAL
PROCEED PREPARE TO STOP AT NEXT SIGNAL
INTERLOCKING SIGNALS
PROCEED ON A DIVERGING MAIN ROUTE
Notes - For use at Junctions
When used in conjunction with a High Home Signal the light of the Dwarf Signal corresponding to the stop indication will be shielded off
INTERLOCKING SIGNALS
PROCEED ON A DIVERGING MAIN ROUTE. PREPARE TO STOP AT NEXT SIGNAL.
Note - For use at Junctions
INTERLOCKING SIGNALS
PROCEED AT LOW SPEED PREPARE TO STOP
R - RED LIGHT
G - GREEN LIGHT
W - WHITE LIGHT

Fig. 22.—Aspects of Signals.

F. L. Dodgson, for the successful development of circuits and mechanism to meet the requirements.

SIGNALING.

In developing the signaling to be used, the then standard practice of the road which combined the use of the two-position lower quadrant semaphore signal for interlocking with the disc signal for automatic blocking, was compared with the three-position upper quadrant semaphore signal for all purposes and the latter was adopted. This made a saving of 60 high signals, left but 90 out of what would otherwise have been 150, reduced the number of signal

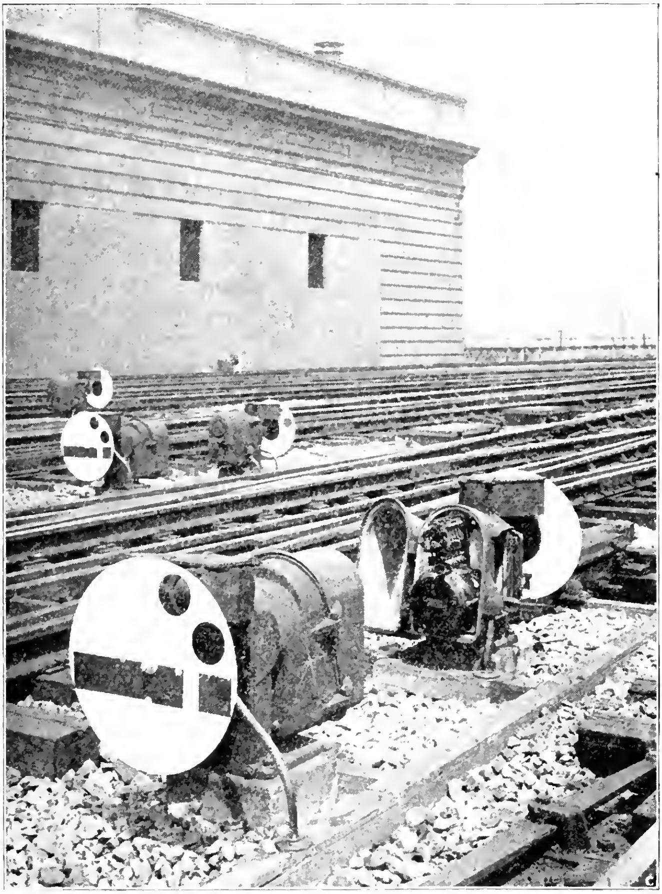


Fig. 23.—Dwarf Signals.

aspects, and simplified the method of giving information to the enginemen. Fig. 22 shows the aspects of the signals used.

By the adoption of this type of signaling and the use of all three positions on the dwarf signals in the Lake Street or terminal plant, we were able, with one signal, to give information of proceed, stop, and as to position of the signal ahead. This was deemed necessary for enginemen and trainmen in the safe handling of trains at reasonable speed, and results have shown the absolute safety and reliability of the practice. At Lake Street we made use of the third position on the last signals governing trains inbound into the depot to indicate that the track under the train shed is clear.

The dwarf signals, Fig. 23, are motor driven and, except at the Lake Street plant, all dwarf signals are used in two positions only, viz., horizontal and diagonal. Figs. 23 and 24 give a good idea of the appearance of the signals.

It will be noted in Fig. 22 that green and red lights are used and a combination of the two, green and red, meaning respectively, proceed, stop, and caution. This combination caution light is peculiar to the North Western System. The lamp used has but one burner and reflector giving the two lights. This was designed in 1889 by Mr. E. C. Carter, Chief Engineer, and has been standard on the road ever since.

At Division Street there are two dwarf signals, each of which govern several routes, one route being a very dangerous one on account of the steep down grade and sharp curvature of the track. To prevent these signals being cleared for the dangerous route inadvertently when some other was intended, each of these dwarf signals is controlled by two levers—one for the dangerous route, arranged so that it must be held reverse by the leverman, while the other governs all other routes and may be left and will remain reversed until put normal, as is the usual practice.

As has been stated, several of the tracks are signaled so that they may be operated in either direction at any time.

In order to insure against trains being started in the opposite direction on one of these tracks at the same time, or against an approaching train, and to provide protection in cases of emergency, should it be necessary to reverse traffic on any of the other tracks, levers are installed in each of the interlocking machines, called traffic levers. These are controlled in the same manner as the signal levers in the manual blocking machines, so that signals cannot be given onto a track until the traffic levers controlling the movements to that track in the tower at either end of it are in the proper position.

COMMUNICATION AND INFORMATION.

Inasmuch as the signaling and interlocking of a large terminal is installed as much for the acceleration of traffic as for its protection, the means of receiving and giving information and of com-

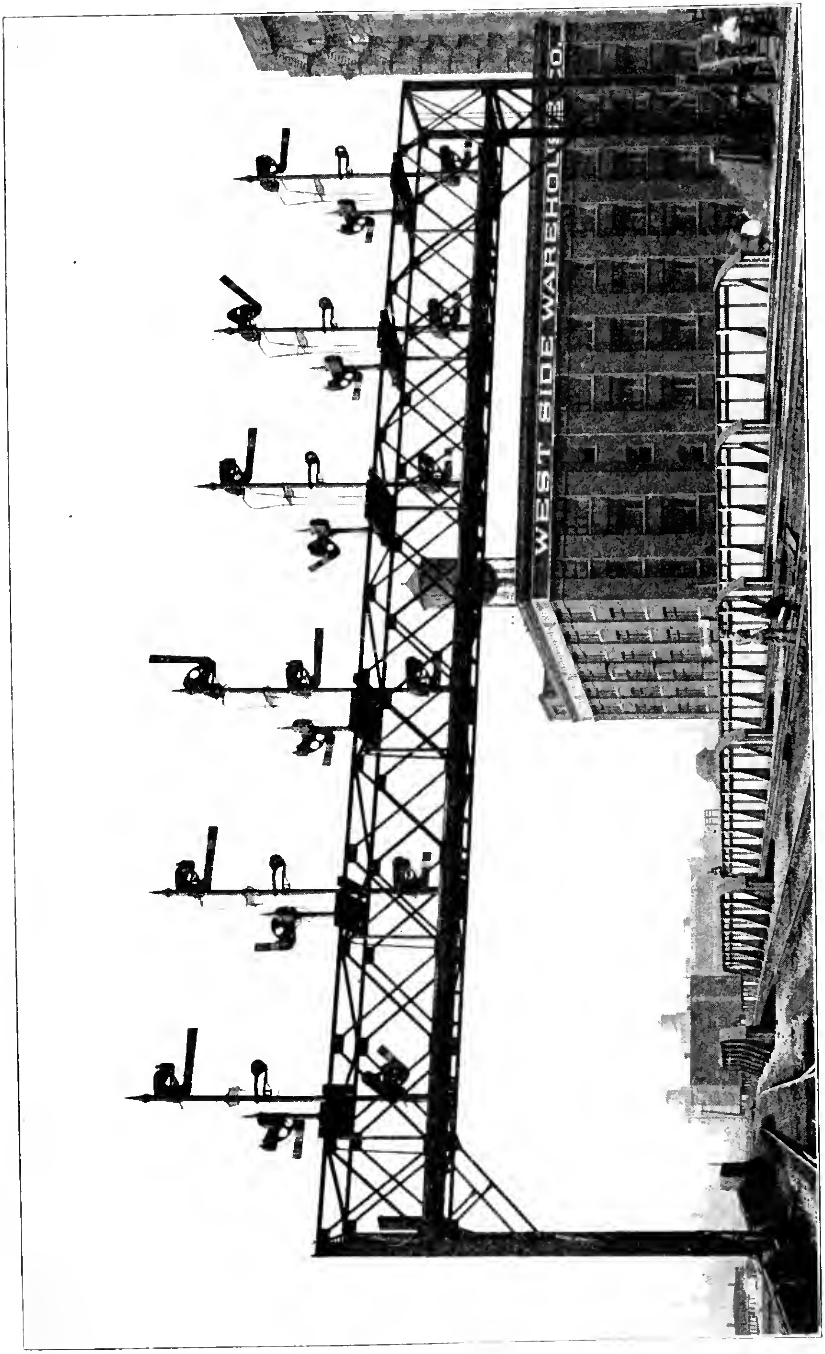


Fig. 24.—Bridge "A."

munication is one of the important features, and was, therefore, given a great deal of attention, and in the solution of the problem almost everything was considered. The telegraph was dismissed from consideration almost immediately, as it restricted too closely the source of supply for levermen to operate the plants and for tower directors. The various means finally adopted and used were:

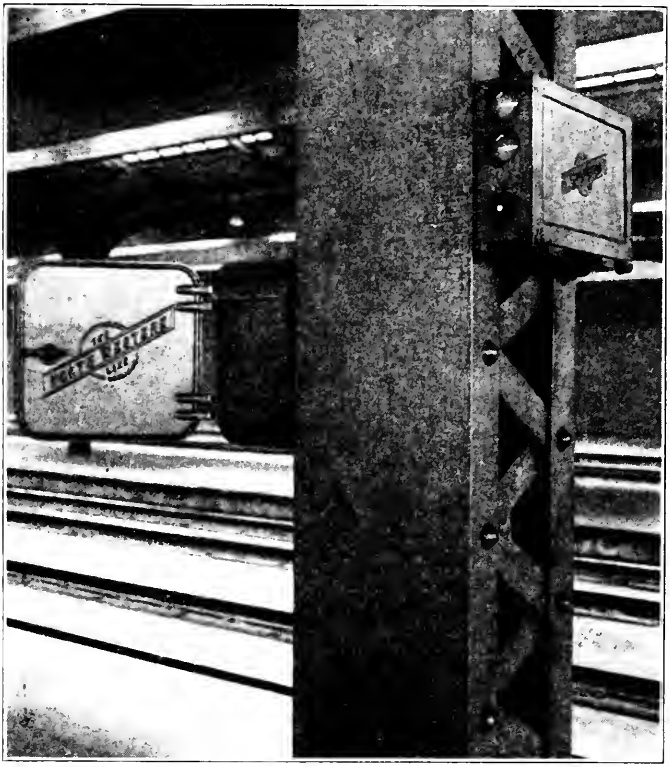


Fig. 25.—C. T. G. Conductor's Box.

Conductors-towermen-gatemen's system of annunciators.
Telautographs.
Various forms of automatic train annunciators and indicators.
Illuminated track diagram.
Lights over levers.
Telephones.
Intercommunicating system.

The Conductors-towermen-gatermen's system, generally called the "C. T. G." system, is for the starting of trains from the depot.

Each of the depot tracks is arranged to hold two trains at one time. Therefore, the equipment for each track is in duplicate in order that each train may be handled without liability of confusion.

In Fig. 25 is shown the conductors' lights and push button mounted in a box on a post on the depot platform. There are four of these distributed along each platform, two for each of the trains which may leave from a track. Each side of each box is equipped in the same way, the two lights and one push button on one side of the box applying only to the nearest track. On the opposite side of the same post is shown the door of a telephone box, two telephones being provided on each platform for the use of conductors, back-up men, etc.

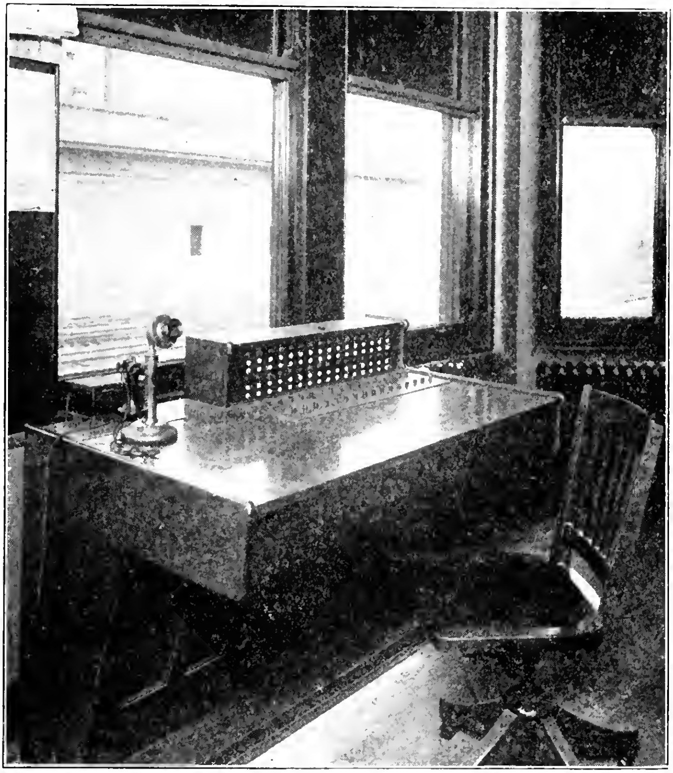


Fig. 26.—Directors' Table, Lake Street Tower.

In Fig. 26 is shown the director's table in the Lake Street tower, with its equipment of three lights and a push button for each of two possible trains on each of the sixteen train-shed tracks.

In Fig. 27 is shown the gatemen's lights and push buttons, the lights being on the concourse and the push buttons on the track side of the gate posts of the partition dividing the main concourse from the train sheds. Fig. 28 shows the circuits used.

In operating the system for through trains, the conductor pushes his button one minute before time for his train to leave. This lights the top light on the tower director's table and the first light of the gatemen's indicators, reminding the tower director and gateman that it is nearly time for the train to leave. The tower director, if he can handle the train on time, immediately pushes his button, which action puts out the top light and lights the second one on his table, puts out the first and lights the second one at the gate, and lights the top light of the conductors' indicators. When it is time for the train to leave, the gateman closes his gates, and after waiting for the last passenger who went through the gate to get on the train or at least giving him sufficient time to do so, he pushes his button. This puts out the second light at the gate, puts out the top light and lights the lower one of the conductors' lights, and puts out the second and lights the third of the tower directors' lights, thus advising the conductor and tower director that the train may leave. The conductor then, and not until then, gives the engineman the signal to proceed,

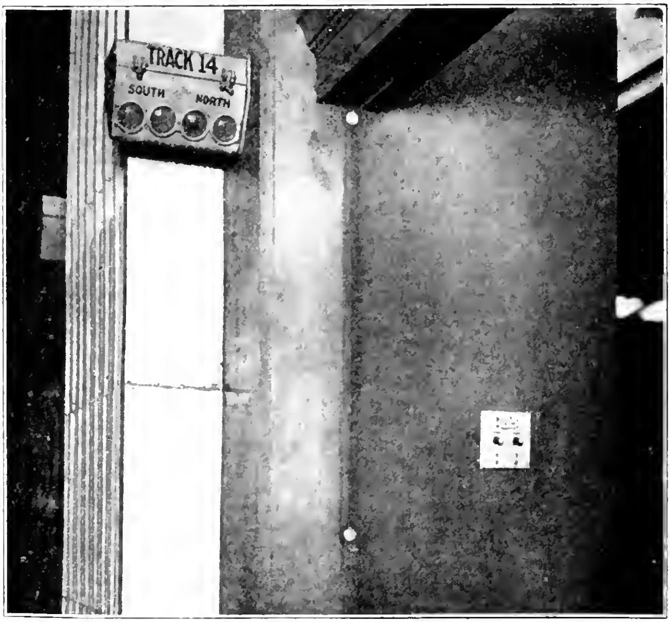


Fig. 27.—Gatemen's Signals.

which he does provided the proper interlocking signal indicates that he may. The restoring of the first interlocking signal to the stop position automatically restores the system to its normal condition ready for the next move.

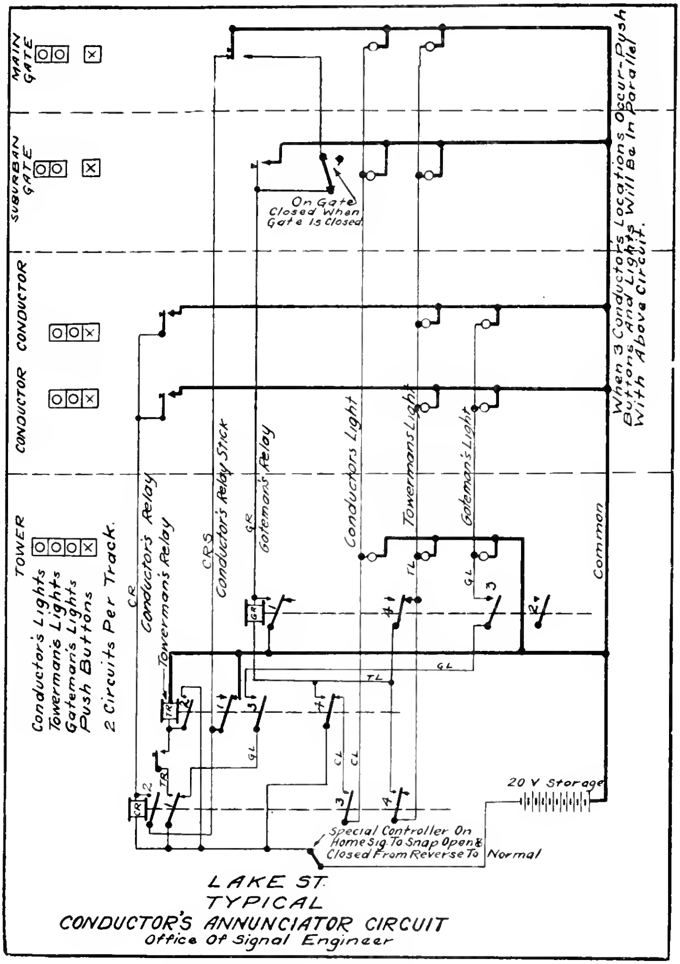


Fig. 28.—C. T. G. Circuit.

For suburban trains, the train conductor pushes his button ten seconds before the time for the train to leave and does not receive any answer as suburban trains must leave on time or congestion would very soon result.

Before a train backs out after discharging its passengers, the conductor or back-up man pushes the conductor's button to indicate to the tower director that he is ready to back his train out, and when the director wishes him to do so, he pushes his button lighting the top conductor's light, indicating to him that he may.

This gives the tower director absolute control of the trains in the depot and allows him to safely put a second train on a track which has for some time been occupied with a train ready to back out.

From the description of the operation of this C. T. G. system, one might imagine that it was complicated, but in actual practice it is simple, rapid, and easily understood.

For the giving of information to all of the employes around the depot who should know about the probable and actual arrival of trains, the Gray Telautograph system was adopted. A single system having three transmitters and nineteen receivers was installed, the transmitters being in each of the two division dispatchers' offices and in the Lake Street tower, the receivers being located as follows:

1 in each dispatcher's office.
1 in the office of Superintendent of Passenger Terminals.
1 on the caller's balcony.
2 on the main concourse.
2 on the suburban concourse.
1 in each information bureau.
1 in each baggage room.
1 in the express office.
1 in the United States outbound mail room.
1 in the United States postoffice.
1 in the railroad mail room.
1 in the redcap boys' office.
1 in Lake Street tower.
1 in Clinton Street tower.

Messages are written in long hand and received in the same way, and while a little practice is required to write plainly, anyone can learn to do so in a very short time.

Inasmuch as the information given on these, especially as to late trains, may be required for some time after being recorded, and after several more messages have been written, the receivers are installed in glass-front cases 6 ft. long. A receiver and transmitter as installed in the Lake Street tower is shown in Fig. 29.

Sometime before a train is due to arrive, the dispatcher records its condition, i. e., whether on time or late, and if late, how much. If the conditions change at any time, the fact is recorded by the dispatcher as it becomes known to him.

When a train is indicated to Lake Street tower from Clinton Street, the fact is immediately recorded on the telautograph with the number of the track on which it will be placed.

By means of this system, every employe about the station may keep informed as to the time and place where trains will arrive and without confusion or loss of time will be at his proper post ready for it.

A second system of two transmitters and two receivers was installed between Lake Street and Clinton Street for handling information that could not be looked out for on the telephones.

As it could not be expected that all the information that might be desired could be given in advance on the telautograph, a telephone was installed with each telautograph receiver connected to the switchboard in Lake Street tower, shown in Fig. 29. To this same switchboard are also connected two telephones on each station platform before referred to, and the old telephone systems connecting the various yard offices, round-houses, and interlocking towers have been connected into this board so that it has now become a small central station, having eighty-four very busy telephones connected to it, and provides a means for which we have long felt the need, i. e., of cross-connecting the various local code lines that had from time to time been installed but which were independent of each other.

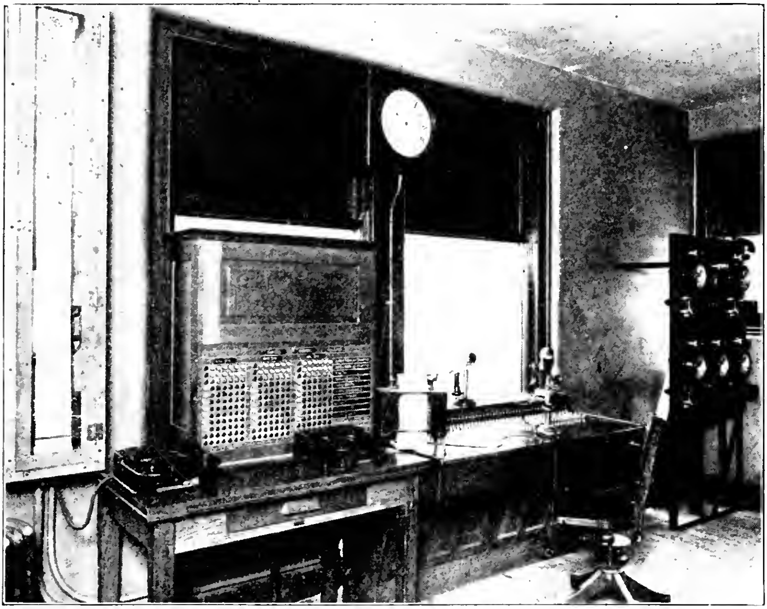


Fig. 29.—Lake Street Tower Furnishings—Operating Board, Telephone Switchboard, Telautograph, etc.

In addition to the telephone system just described, there is a local system at each plant. A single pair of wires is installed for this purpose with a permanent telephone in the work-room and one in the operating-room of each tower, and a place where a portable telephone may be connected by means of a jack, in the relay-room, and in or on each of the principal manholes or junction boxes throughout the plant. A permanent telephone was also installed on each home signal bridge connected to the local circuit.

By means of these local systems, a trainman may communicate with the towerman without having to go to the tower; a repairman may do likewise or two of them may, by plugging in portable telephone sets, communicate with each other between any parts of the plant. When the size and, therefore, amount of ground covered by these plants is considered, the necessity for such means of communication will at once be realized. A telephone line for direct communication between adjacent towers is also provided.

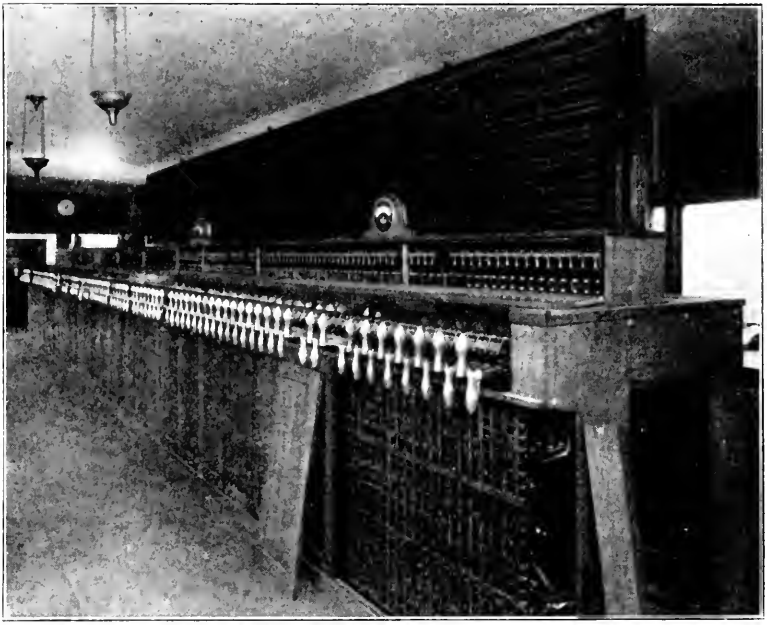
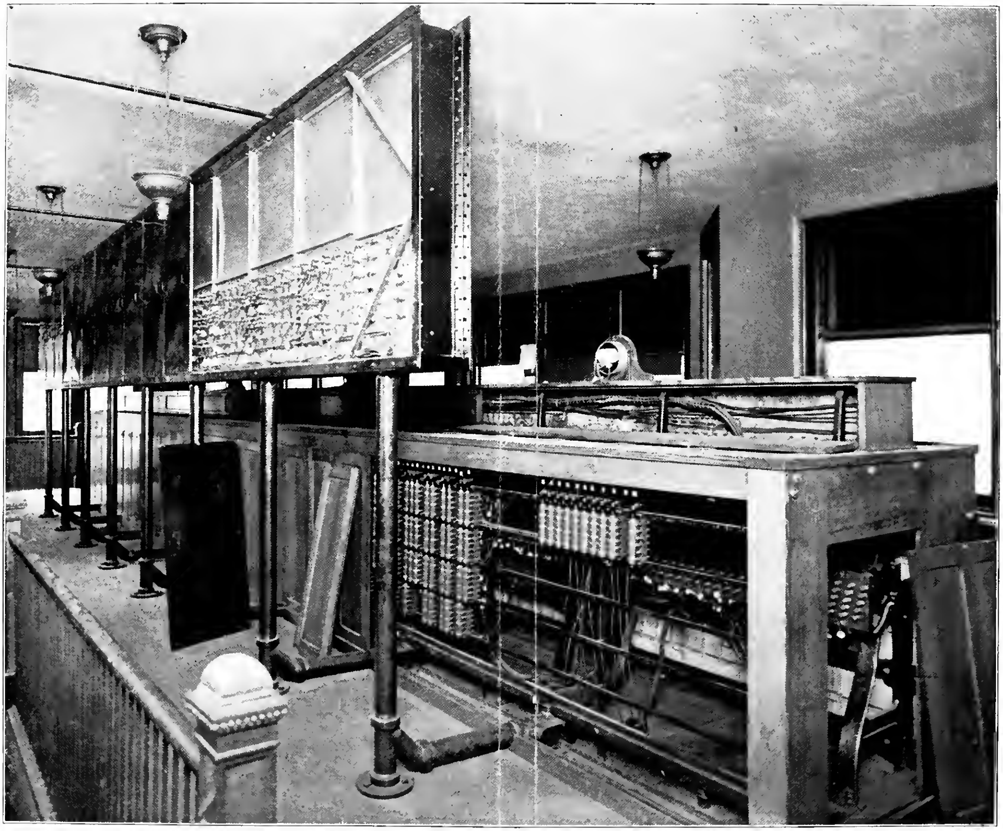


Fig. 30.—Interlocker, Front View.

A small push button switchboard is installed in each tower except Lake Street, so that one permanent telephone set in the operating room may be connected into any one of the telephone lines. These switchboards are so constructed that two permanent telephones in one tower may be used at the same time connected onto

Plate XVII.



Rear View of Interlocker.

separate circuits; also any two telephone circuits may be connected through.

To give the towerman information of the proximity of approaching trains, annunciators were installed in each tower. These are relays having a small disc and a vibrating bell attached, and they are controlled automatically by means of the relays of the track circuits for some distance on each track on which trains approach the plant.

The occupancy of the detector circuits elsewhere described is indicated by means of a small light mounted under a ground glass over each switch lever. When the light is burning the track is free, but when the light is out the track is occupied and the lever must not be moved.

In addition to the lever lights, illuminated track diagrams were installed in Lake and Clinton Street towers. The front view of the one in the Lake Street tower is shown in Fig. 30, and the back view is shown in Plate XVII. The front of these diagrams is made up of ground wire glass. The tracks, signals, switches and their respective numbers are in yellow; the ends of the track circuits are indicated with black lines, and the space between tracks is filled in with dead black. Behind the glass face are tin boxes, mounted on an aluminum back. These tin boxes average 4 in. deep, 4 in. long, and ½ in. wide, and each contains one 4-watt 14-volt lamp. By this means the illumination of each lamp is confined to the space directly in front of it. The lights are controlled in a manner similar to the lever lights, so that when there are no trains in the plant, the entire track lay-out is illuminated, and as a train passes through the plant its progress is clearly shown by the lights going out as it successively occupies the different track circuits and by the lights again appearing behind the train as it leaves them. The occupancy of the depot tracks and of the tracks adjacent to each plant is shown in the same manner. The route lined up through each switch is indicated by means of lamps controlled through circuit breakers on the switch levers. The information is so clearly and completely shown in the illuminated diagram, that it will be possible on a stormy day and always at night to operate this terminal without the towermen seeing the trains.

For giving information from one tower to another of a train move and something as to its character, a push button scheme was developed which has been named the "Intercommunicating System." Directly in front of the window to the left in Fig. 29 is shown the case in Lake Street tower.

The indication on these boards is made by small telephone lamps arranged in horizontal rows and columns as shown in Figs. 29 and 31. The columns represent the track numbers, and the rows the various classification of trains. The boards were made to suit local conditions and are entirely of standard telephone apparatus.

Between Lake and Clinton Streets all train movements are governed from Lake Street tower. When a train is to move from Clinton Street to Lake Street, a button is pushed in the Clinton Street board, telling the kind of train and the division, and energizing a relay in the Lake Street board, which in turn energizes a lamp in the Lake Street board in a corresponding position. The relay is held energized by its own front contact and is released only when a button in the same row is pushed at Lake Street, indicating to Clin-

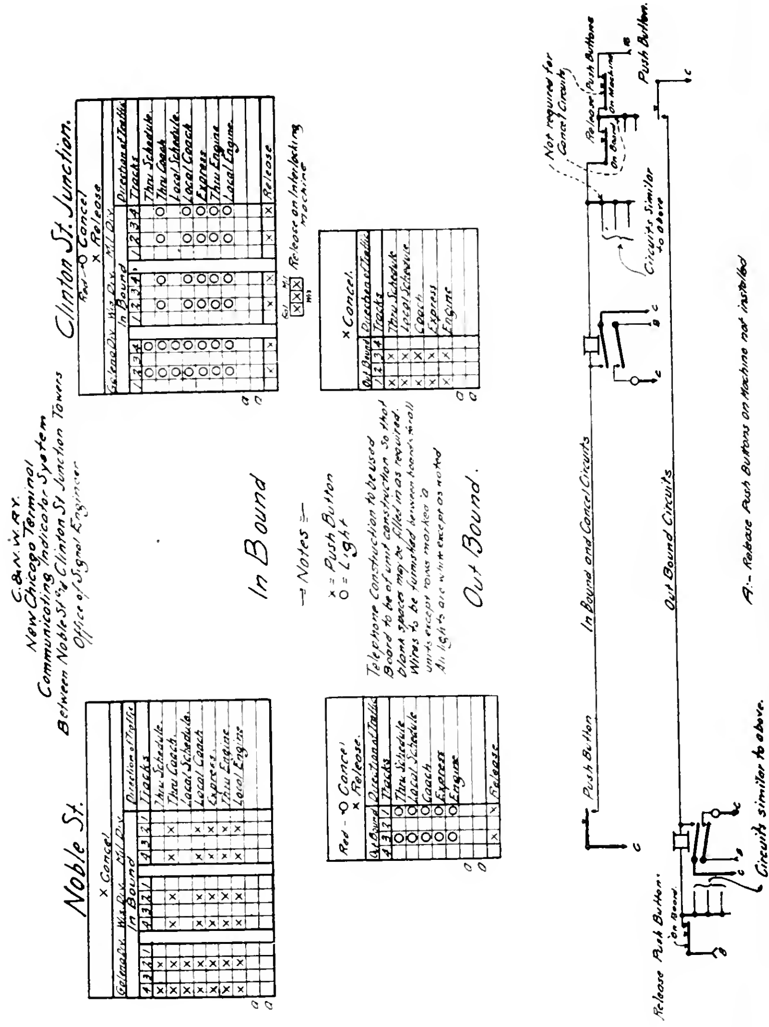

C. & N. W. RY.
New Chicago Terminal
Communicating Indicator System
Between Noble St. and Clinton St. Junction Towers
Office of Signal Engineer
Noble St.
Clinton St. Junction.
Red - O Cancel
X Release
X Cancel
Galena Div.
Wis. Div.
Mil. Div.
In Bound
Out Bound
Direction of Traffic
Tracks
Thru Schedule
Thru Coach
Local Schedule
Local Coach
Express
Thru Engine
Local Engine
Coach
Engine
Release
Release on Interlocking Machine
In Bound
Out Bound.
Notes:-
x = Push Button
O = Light
Telephone Construction to be used. Board to be of unit construction so that blank spaces may be filled in as required. Wires to be furnished between boards in all units except rows marked a. All lights are white except as noted.
Not required for Cancel Circuits
Release Push Buttons
On Board
On Machine
Push Button
Circuits Similar to above
In Bound and Cancel Circuits
Out Bound Circuits
A:- Release Push Buttons on Machine not installed
Circuits similar to above.
Release Push Button
On Board

Fig. 31.—Circuits Intercommunicating System.

ton Street what track to send the train on. In sending a train from Lake Street to Clinton Street, the button at Lake Street alone is pushed, indicating to Clinton Street on what track the train will come. The lamp at Clinton Street is lighted in a similar manner and is put out by pushing a release button at the foot of the column.

There is also a cancel button on each board with its corresponding light and a release button on the other board. These are used when an indication has been given and the traffic is of a different kind or when the routing must be changed. The circuits are similar to the other circuits.

At the top of the boards for the Lake Street and Clinton Street system there are two rows of lamps showing the direction of traffic. These are energized through contacts on the traffic levers.

The system between the other towers is similar except that push buttons and lights are only provided for the giving of information as to the approaching trains from one tower to the next.

INTERLOCKING MACHINES.

The interlocking machines are the standard unit lever type as manufactured by the General Railway Signal Company.

Some slight changes were made to meet the requirements, provision having to be made for the lever lights by means of which the condition of a track circuit is indicated, and for the combination board on the back of the machine, by means of which the low voltage circuits are controlled. Fig. 30 and Plate XVII show quite clearly the general construction and appearance and something of the details of the interlocking machine in the Lake Street plant. Fig. 32 shows the details of construction of an interlocking lever, and from it may be obtained an idea of the complexity of these machines. The case is of oak and entirely encloses the machine. Each door is provided with a hasp, and these are kept sealed so as to prevent improper manipulation.

TRACK AND CONNECTIONS.

The method of connecting the switch movements to the switches, movable point frogs, and derails is clearly shown in Figs. 33, 34, 35, 36 and 37. The General Railway Signal Company's standard No. 4 movement was used for everything except derails, for which their standard No. 2 movement was used.

No detector bars were employed on the switches, derails, etc., of the Lake and Clinton Street plants, detector circuits only being relied on to protect against the throwing of these functions under trains. In the other three plants, where the speed of trains is on an average much higher, both detector bars and detector circuits are employed. When detector bars were not used with the No. 2 movement, a spring was applied on each movement to take its place in insuring that vibration would not operate the movement sufficiently to unlock the derails if the control circuit were broken.

The track circuits used as detector circuits were made as long as possible consistent with operating conditions, in order to cut down as much as possible the total number of track circuits required and also in a measure provide against slow-acting relays. Fear of the relays acting slowly seems to have been unwarranted, however, as the relays employed are so quick in action that there is no question as to the protection given by them.

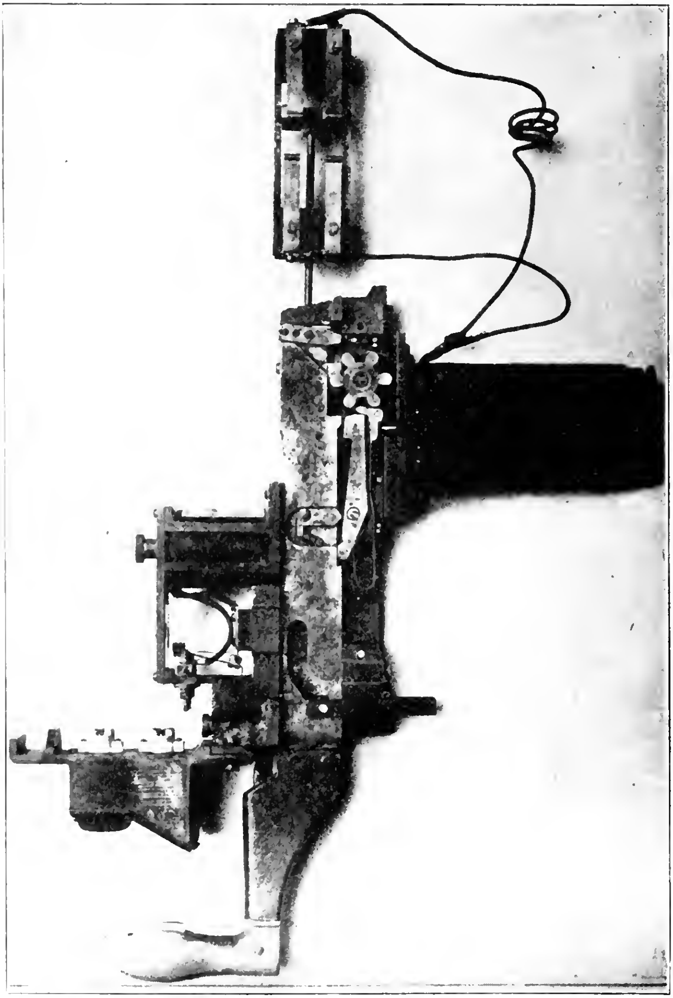


Fig. 32.—Construction of Interlocking Lever.

The bonding of the rails is that ordinarily used for signal track circuit purposes, viz., two No. 8 galvanized iron bond wires

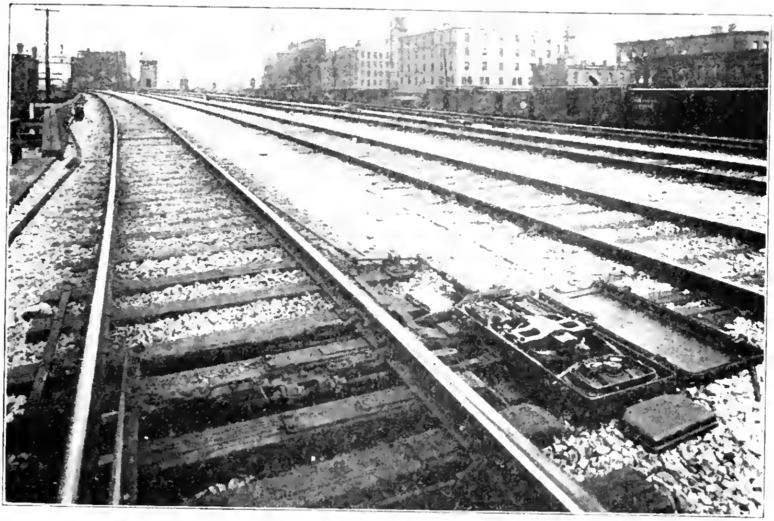


Fig. 33.—Single Switch.

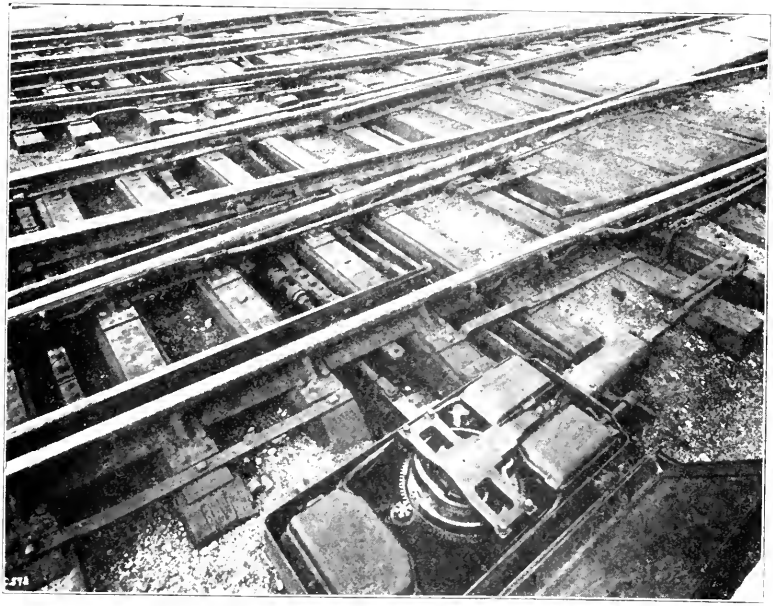


Fig. 34.—Double Slip Switch.

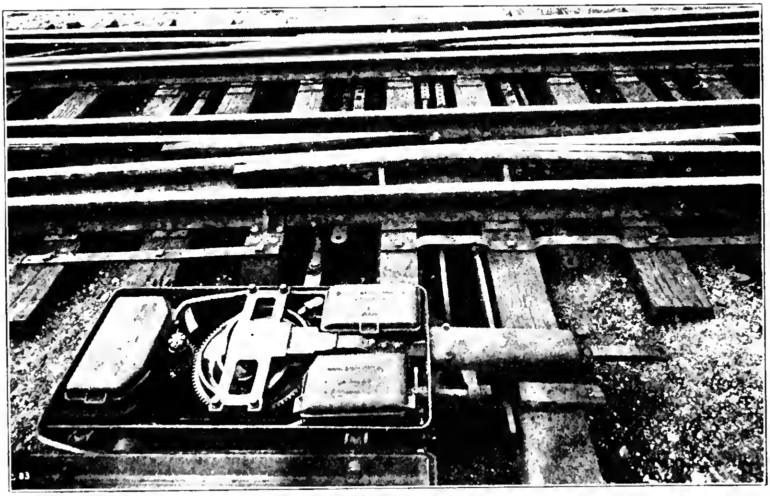


Fig. 35.—Movable Point Frog.

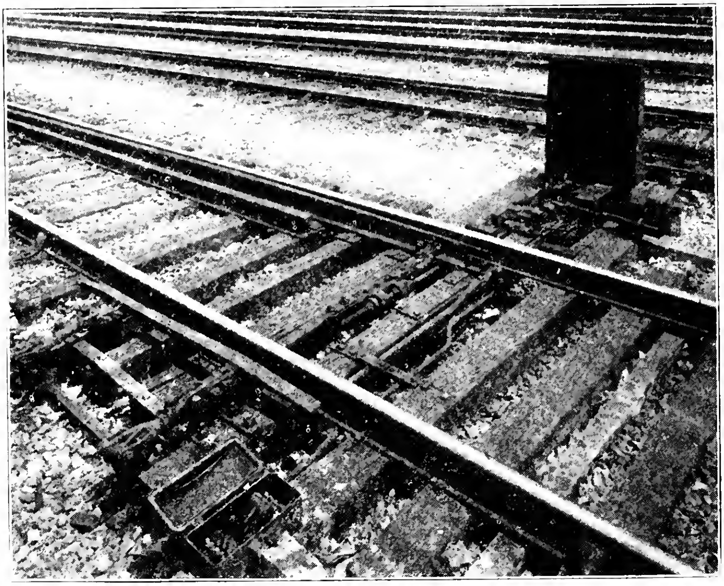


Fig. 36.—Continuous Track Derail.

around each joint and fastened to the rails by means of channel pins driven into holes 9-32 in. in diameter.

Continuous rail insulated joints were used. The switch rods are insulated and the switch tie plates cut so as to leave a space of not less than two inches between the ends, as experience, covering a period of several years, demonstrated that the strength of a continuous plate between two rails is not required; also, the cut plate is much cheaper both in first cost and maintenance and can be inspected for insulation without difficulty.

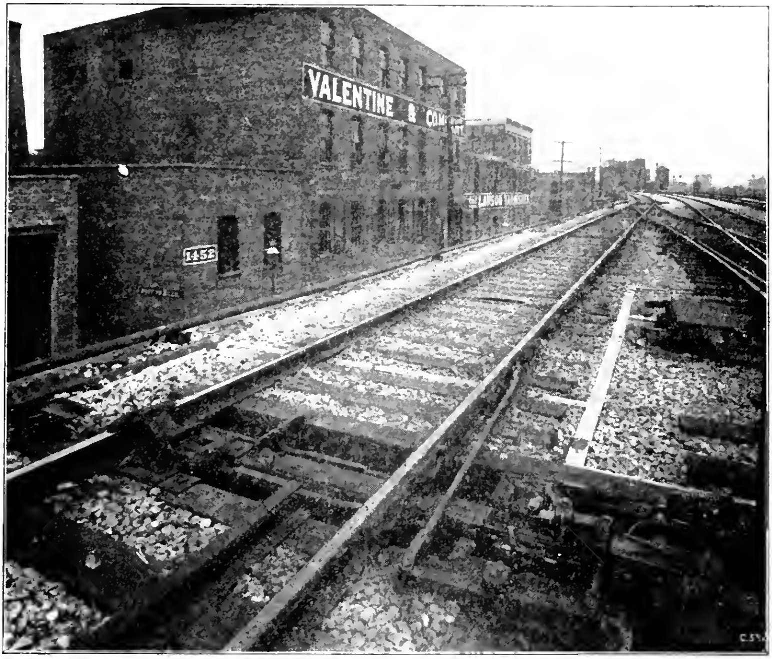


Fig. 37.—Hayes Derail.

OPERATING BOARD CIRCUITS.

The operating switchboard shown in Fig. 29 and circuits in Fig. 38 contain the main protection used for the interlocking apparatus.

The power wires from the main power switchboard pass through this board to the interlocking machine. The ammeter is inserted in the positive wire. By means of this ammeter the leverman may watch the current used to operate the switches and signals, and can tell whether they are working properly.

At Lake and Clinton Streets, several ammeters are placed on the turret of the interlocking machine instead of the one on the operating board, each meter for a section of the machine, so that the leverman may never be far from the one controlling the section in which he is operating.

The positive current is fed to the bus bars located on the interlocking machine from which all functions receive current.

The negative is split into sections, depending upon the size of the plant. From here the negatives are called common and each of these commons passes through a circuit breaker on the operating switchboard. Each circuit breaker is controlled by a polarized relay on the board and one on the interlocking machine for each lever, controlling units in the section of the plant fed by that common. Whenever current flows through the polarized relays in the opposite direction to that in which the indication current flows, due to a cross or ground, the polarized relay will open up, in turn opening the circuit breaker and cutting power off from that section of the plant. If the current still exists, it will find a path through the relay (a) which is in multiple with the points of the circuit breaker; this relay (a) being energized, it lights a red lamp as a warning and energizes relay (b), which opens the main circuit, so that closing the circuit breaker will not restore current so long as the trouble exists. Clearing of the trouble automatically puts out the red light and closes the circuit.

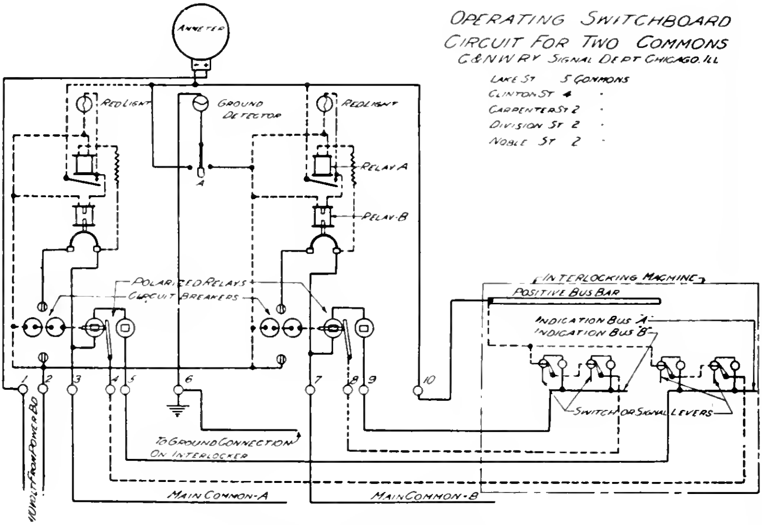


Fig. 38.—Circuits—Operating Board.

A 110-volt 2 candle-power lamp with a suitable switch is used as a ground detector.

DWARF SIGNAL CIRCUITS.

The dwarf signals are of the model 2-A General Railway Signal Company's type. The motor is geared directly to the spindle on which the blade is mounted, and to which are also connected springs to force it back to the normal position when released. While running backward the motor generates current which energizes the indication magnet and releases the lever. The load imposed on the generator brings the mechanism to an easy stop, accomplishing the result of a dash-pot.

Common or return wires for dwarf signals pass through switch boxes on all facing derails to insure that the derails are off from the track before the signal can be cleared.

HIGH SIGNAL CIRCUITS.

Fig. 39 shows the following:

(a) High voltage (110-volt) home interlocking signal with low voltage 90° position control.
(b) Low voltage approach signal (automatic).
(c) Back locking from approach signal.
(d) Advance locking.
(e) Lights on signal levers.

The high signal motor is the same type as the dwarf signal, the interlocking signals being 110 volts.

All the high signals are slotted, i. e., automatically put to stop when a train passes. This is accomplished without the use of the usual slot magnet. The control circuit of the signal is opened by the slotting relay (f) and immediately closed on the indication magnets, regardless of the position of the lever. The motor being deprived of current turns backward and generates current sufficient to energize the indication magnet. The signal may also be put to stop position by putting the lever normal.

The common or return wire from the signal motor is selected through all derails and facing point switches in the route as a check on the position of the switches.

The high signal is held clear by cutting in extra field coils at the 45° and 90° positions, which with the other coils are just able to hold the armature without motion.

Current for operating the signal from 45° to 90° is taken from the control wire locally and is controlled by a line relay. The control of this relay passes through the slotting relay and signal lever, and is selected through the proper switch levers to the next signals in advance, where it passes through a circuit breaker closed from 45° to 90° to battery.

The approach signal is of a type similar to the interlocking signals previously described but operates on 16 volts instead of 110 volts. As these signals do not furnish dynamic indication, a snub circuit is provided which closes at the proper times when the blade is descending to stop the mechanism gently. The signal is held clear

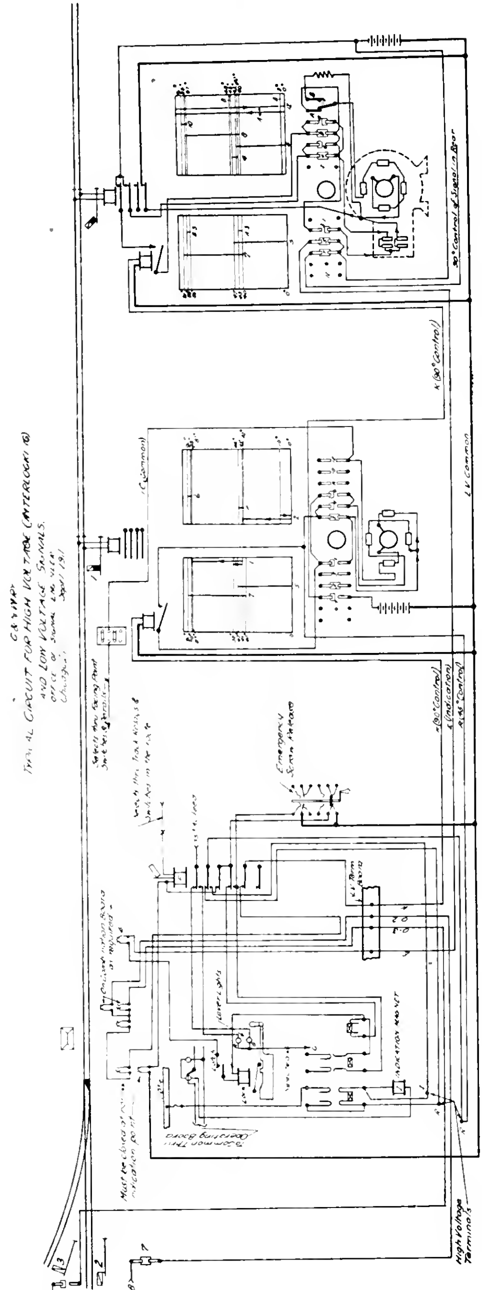


Fig. 39.—Circuits for High Voltage Home and Low Voltage Approach Signals.

by a clutch arrangement instead of by the extra fields as used with the high voltage signal. The normal indication of the approach signal is given by an electric lock located on the top of the home signal lever and locking it at the normal indication point, battery being furnished at the approach signal. The circuit is closed by a contact on the approach signal closed at or below the 45° position. Other than giving this normal indication, the approach signal is the same as any other automatic signal.

The return indication lock is also used for approach locking, current being withheld from the lock until the train has passed the home signal by having the circuit open when the track between the approach and home signal is occupied. A release is provided to restore the lock in case it is desired to change a route after the signal has been given. This requires either that two men shall work togther or that a certain length of time shall elapse, both intended as a check on the men's actions and to give time for a train to be stopped after a signal is put against it before the route can be changed. The approach locking is in addition to the route locking described elsewhere, and is used on routes governed by high signals only.

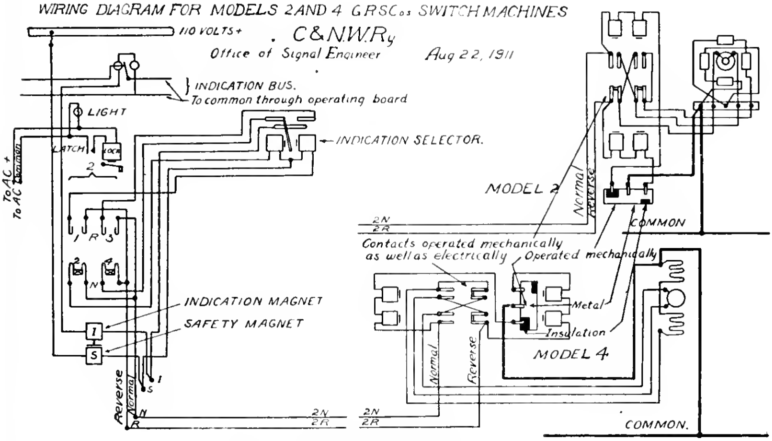


Fig. 40.—Switch Machine Circuits.

The lights on the signal levers are selected through switch levers and relay points to accomplish the following:

No light when there is no route lined up.

Green light when there is a route lined up that is unoccupied.

Red light when there is a route lined up that is occupied.

SWITCH MECHANISM WIRING.

In Fig. 40 is shown the switch machine operating circuits which are standard for this type of interlocking.

TRACK CIRCUIT FEED.

The track circuits for the interlocking plants are fed by means of loops, as shown in Fig. 41, from the 20-volt storage batteries located in the towers. Two positive and two negative wires are run from the low voltage distributing board, Fig. 42, to the junction boxes in the section of the plant to be fed. The wires of the same polarity are joined at the end, thus forming loops so that current from the switchboard has two paths to any point on the loop. The loop wires can break at any place, and every point would still receive current.

On the switchboard, ammeter jacks are placed for each wire and again for the main feed wires after the loop wires have joined. A regulating rheostat is inserted in the positive lead capable of cutting the battery down to about 12 volts, at which point it is generally maintained. The track sections are fed from various points on the loop through resistance units placed on each side. These are in most cases 37.5 ohms, although on some sections the resistance has been reduced on one side to meet local conditions. These resistances are of the enclosed fuse type mounted on the terminal boards of junction boxes and manholes. During wet weather, when the leakage between rails increases, the regulating rheostat may be used to allow more current to flow to compensate for this leakage. The purpose of the ammeter jacks is to determine when a break occurs in any of the loop wires. As long as the circuits are perfect the readings are the same, while if there is a break the readings on the No. 1 and 3 wires will be different from the readings on the No. 2 and 4 wires respectively.

In calculating the size of the wire for the loops, one side of each loop was considered cut off at the switchboard and every track circuit occupied except the one nearest the cut-off end.

The voltage required on this last track circuit must be enough to pick up its relay. The voltage on the switchboard being 12, the current used by each shunted track circuit being known, the size of wire is easily worked out. The practicable limit to the number of track circuits that could be fed from a loop was found to be 20. Relays of 12 ohms are used on all circuits fed from the track circuit loops. A 12-ohm resistance unit is located in series with the relay to obtain a quick drop-away of the armature, the time being reduced 50% by the insertion of this resistance. This is very desirable on account of the detector locking.

Where the track sections are adjacent to the towers the track relays are located in the tower, but where they are too far away for efficient operation, repeater relays are placed in the tower and controlled by the track relays which are placed adjacent to the track sections.

For the train-shed track circuits two 110 volt to 20 volt direct current to direct current motor generator sets were installed in a

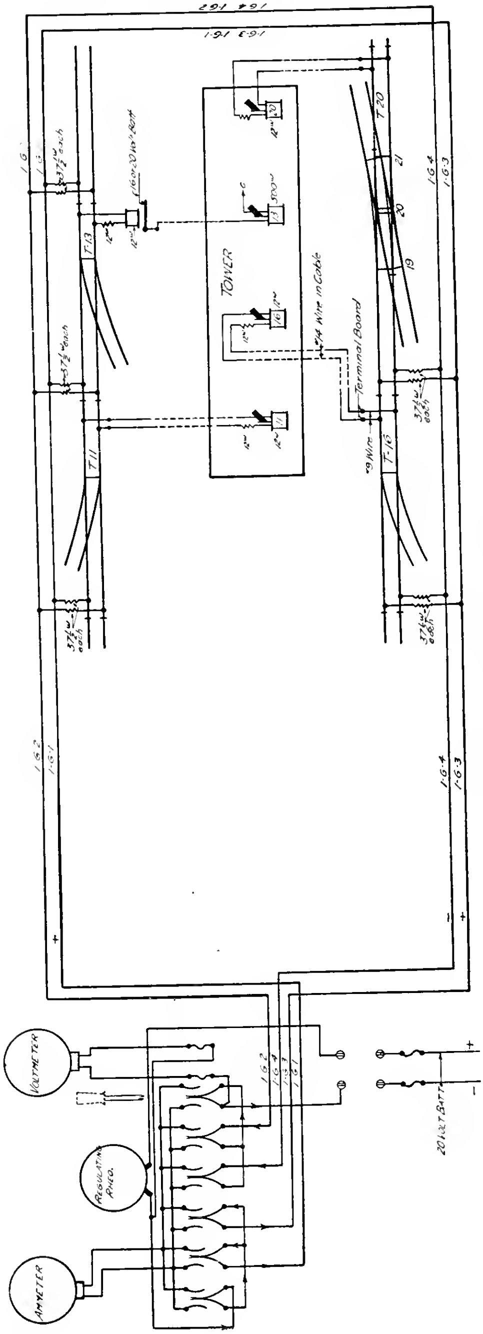


Fig. 41.—Track Circuit Feeds.

relay room under the station platform. These feed direct to the tracks, no storage battery being used, and the sets are run successively in six hour periods.

These motor generator sets are run off the depot lighting system, and by using them instead of a rheostat, the lighting circuits and track circuits are kept separated, and any grounds which may occur on one will have no effect on the other.

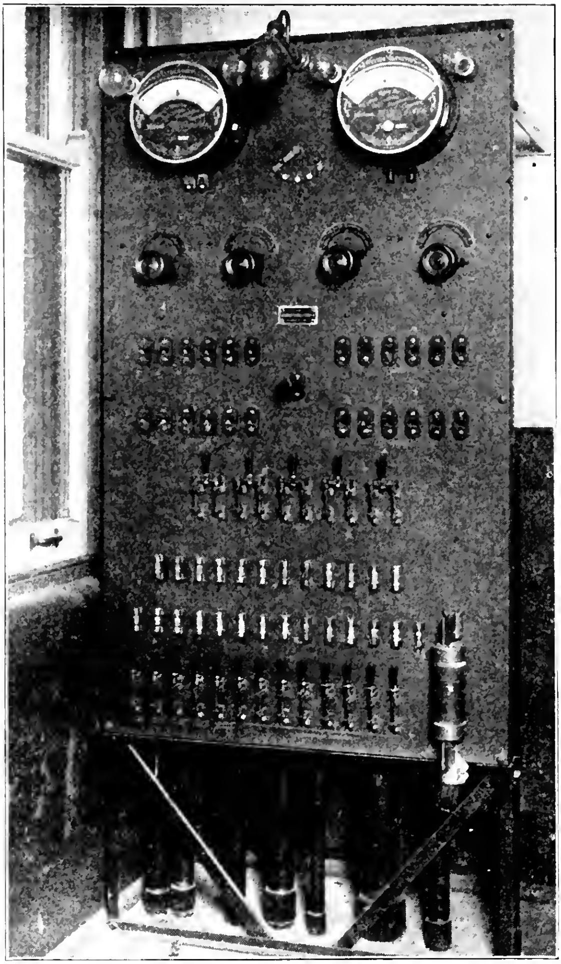


Fig. 42.—Low Voltage Distributing Board.

At the signal bridges at which power-houses are located, the track circuits are each fed from a single cell of 120 ampere hour capacity storage battery with an 8-ohm resistance in series. Relays of 4 ohms are used where the track circuit is fed from these individual cells.

RELEASE ROUTE LOCKING.

The release route locking circuits employed were used for the first time on this installation and are much simpler than any heretofore used to accomplish the same purpose. These circuits were applied only at Lake, Clinton, and Division Streets, these plants being the largest and having very congested traffic.

The operation is as follows: A train entering a route locks up all switches, derails, and movable point frogs in the route, and when the train leaves each track section, all switches, derails, and movable point frogs in that section are released so that they may be moved.

This result is accomplished as follows: The circuits are divided into two general classes,—the stick relay circuits and the lock circuits. The stick relay circuits are composed of the stick relay pick-up and the stick relay stick-up wires. The lock circuits are composed of the battery feed wire and the lock wire. The direction in which the locking takes effect is determined by the position of the stick relay, the relay being up when the train is going in one direction and down when going in the other. The relay is picked up by a contact on the signal governing in the direction requiring the relay up, and is then held up by back contacts on the track relays in the route. The signal in the opposite direction does not pick the stick relay up and consequently it remains down. It will be readily seen that restoring one signal to normal position and clearing the opposing signal will reverse the route locking. This is valuable for switch-engine moves and also for those trains which are too long to completely enter the station and clear the last switch circuits of the interlocking plant.

The levers are controlled by electric locks located on top of the lever, the circuit being held normally open by a contact operated by the lever latch. A white light is in multiple with the lock and latch contact, showing at all times whether the lock can be energized or not. Each lock is controlled directly by the track relay of the section in which the switch is located, thus providing absolute detector locking, making it impossible to operate a switch lever, and therefore the switch, when the section in which that switch is located is occupied. The lock wire receives battery from a back contact of the stick relay while battery is fed to the other end of the route over the battery feed wire, when the stick relay is energized, through the front point of the relay. Thus it will be seen that when a train is going in the direction that the stick relay is energized, battery is fed behind the train as it proceeds. When the train is proceeding in the opposite direction, the stick relay being de-energized the current is also fed from behind the train. Thus we always have the switches

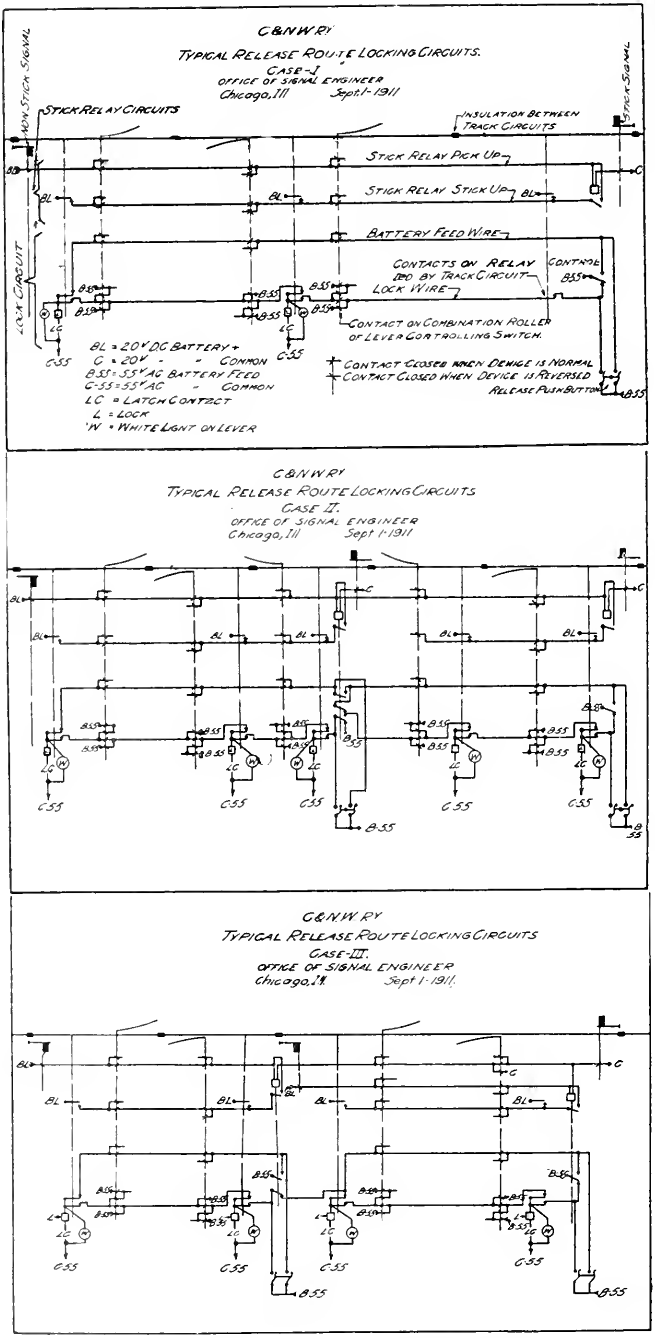

C&NW RY
TYPICAL RELEASE ROUTE LOCKING CIRCUITS.
CASE-I
OFFICE OF SIGNAL ENGINEER
Chicago, Ill Sept. 1-1911
NON STICK SIGNAL
STICK RELAY CIRCUITS
INSULATION BETWEEN TRACK CIRCUITS
STICK SIGNAL
BL
C
STICK RELAY PICK UP
STICK RELAY STICK UP
BATTERY FEED WIRE
CONTACTS ON RELAY FED BY TRACK CIRCUIT
CONTROL
LOCK WIRE
LOCK CIRCUIT
CONTACT ON COMBINATION ROLLER OF LEVER CONTROLLING SWITCH.
B55
LC
C-55
BL = 20V DC BATTERY +
C = 20V " COMMON
B55 = 55V AC BATTERY FEED
C-55 = 55V AC " COMMON
LC = LATCH CONTACT
L = LOCK
W = WHITE LIGHT ON LEVER
CONTACT CLOSED WHEN DEVICE IS NORMAL
CONTACT CLOSED WHEN DEVICE IS REVERSED
RELEASE PUSH BUTTON
C&NW RY
TYPICAL RELEASE ROUTE LOCKING CIRCUITS
CASE II.
OFFICE OF SIGNAL ENGINEER
Chicago, Ill Sept 1-1911
BL
C
B55
LC
W
C55
B-55
C&NW RY
TYPICAL RELEASE ROUTE LOCKING CIRCUITS
CASE-III.
OFFICE OF SIGNAL ENGINEER
Chicago, Ill. Sept 1-1911.
BL
C
B55
L
LC
W
C55
B55

Fig. 43.—Release Route Locking Circuits.

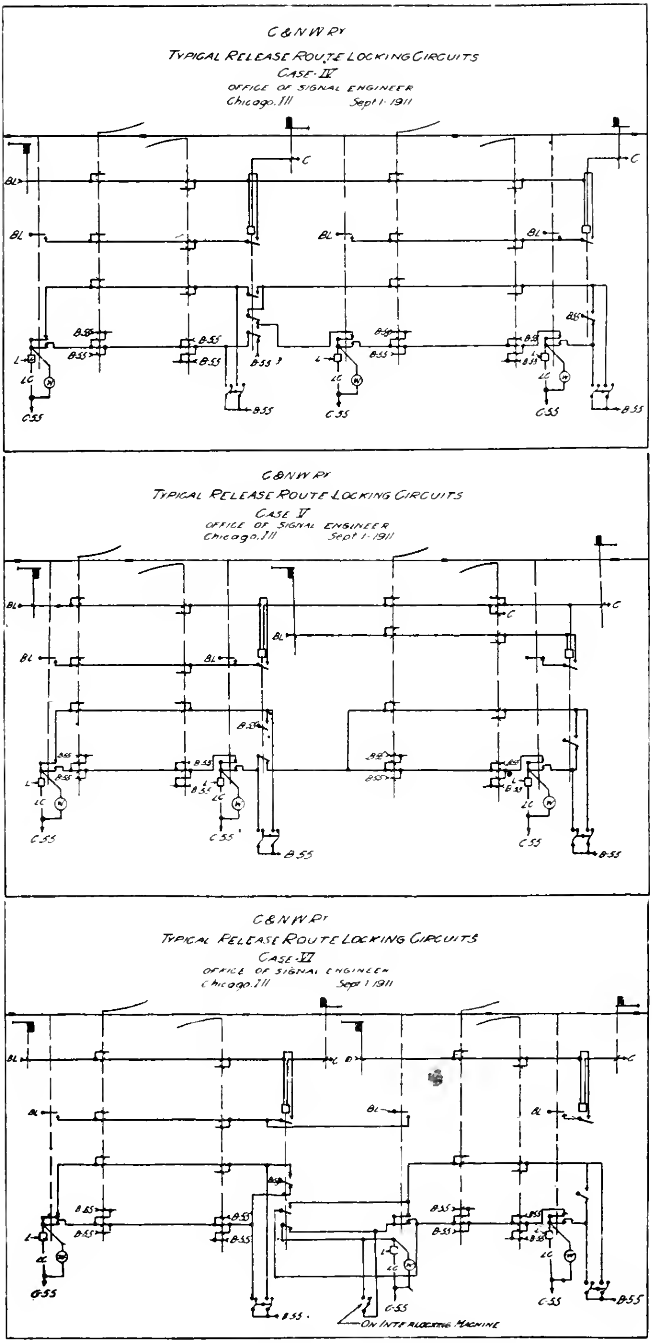

C&NW Ry
Typical Release Route Locking Circuits
Case-IV
Office of Signal Engineer
Chicago. Ill Sept 1-1911
BL
C
B-55
L
LC
W
C-55
C&NW Ry
Typical Release Route Locking Circuits
Case V
Office of Signal Engineer
Chicago. Ill Sept 1-1911
BL
C
B-55
L
LC
W
C-55
C&NW Ry
Typical Release Route Locking Circuits
Case-VI
Office of Signal Engineer
Chicago. Ill Sept 1 1911
BL
C
B-55
L
LC
W
C-55
On Interlocking Machine

Fig. 44.—Release Route Locking Circuits.

and derails locked ahead of and under the train while those which are behind the train are unlocked. In case it becomes necessary to change a switch or derail ahead of a train which has come to a stop, current may be supplied to all locks in the route except those under the train by means of a push button so located in the tower that it requires one man to operate it while the leverman is operating the lever, thus bringing two men into the operation. All circuits are selected so that they fit together without duplication of wiring. Each stick relay is located at the same relative end of the circuit for each plant. The stick relay circuits are fed from the 20 volt D. C. storage battery.

The various circuits illustrated show the special conditions which had to be taken care of and methods of doing so. See Figs. 43, 44.

Closely associated with the release route locking is the mechanical locking, which must be sufficiently flexible to allow the releasing to be effective and rigid enough to give protection to the trains.

In the Lake Street interlocking, signal locking only was used, i. e., signal levers lock their routes and switch levers do no locking except in a few special cases.

In Division and Clinton Street plants, derail levers are used for locking the routes, and a system of locking was devised which allows very nearly the complete release effected by the electric locking and still retain the derail protection. In this case, all facing derails lock the trailing derails and the facing points switches in their routes. If the plans are studied, it will be noticed that when this is accomplished it is impossible to line up a derail of a conflicting route, thus affording derail protection. As for releasing, it will be noticed that when a derail is passed, it is released. When a trailing point switch is passed, it is released. When a cross-over, both switches of which are connected to one lever, is passed over in the reverse position, it is released on passing the second pair of points. A facing point switch, however, is not released but in most cases it may be released by moving the next trailing switch after it is passed.

At Clinton Street, where two derails are used in some cases the slow speed derail does all the mechanical locking. In order to insure the operation of the high-speed derails, the circuits of conflicting high signals are controlled by the derails.

This type of electric locking was not used at Carpenter and Noble Street plants, but the route ahead of a high speed train was locked, allowing release behind or not as was found simplest. On all slow-speed moves, detector locking only was required, although more was sometimes effected incidental to the high-speed routes.

On these two plants, the mechanical locking is as follows:

Derails lock all switches in route.
High-speed derails lock back-up derails.
Derails of same class, lower number locks the higher.

Where special release is required, mechanical locking is transferred from derails to signals to allow necessary freedom.

INSTALLATION OF WIRING.

On account of the number of circuits, requiring a great mass of wires, it was necessary to do the work mechanically, i. e., furnish detailed plans showing exactly how each piece of work was to be done, the workmen being required to follow these plans without any knowledge of the circuits involved.

Terminal board plans were made for every junction box and manhole, as per Fig. 45, showing the wires to be spliced through, the wires to go to terminals, the location of terminals and resistance units.

In the same way, plans were made of terminal boards for junction boxes on signal bridges and for those located in the towers.

Plans of the conduits were made, showing location and size of each. Tables were furnished showing the number and size of wires in each duct, the total length of each wire, and the number of feet to be left out at each end. The number of each wire and its destination was also shown.

Plans were then furnished of the back of the relay racks, the combination board, interlocking machine proper, the release buttons, etc., showing the details for connecting the wires and using the tag numbers described above to identify them.

The circuit sheets were written instead of drawn, and by description or number gave each connection to be made and each cable or conduit through which a wire ran. Fig. 46 shows this method of writing circuits. This work of the drafting room saved an immense amount of work in the field.

BRIDGE POWER HOUSE SWITCHBOARD CIRCUITS.

The motor-generator set provided for charging the storage batteries located at the signal bridges is shown in Fig. 47.

The batteries being in duplicate, each set of battery has a charging switch so arranged that the load is never deprived of battery. The switch is constructed so that either set of battery may be discharged with the other on open circuit or being charged. In accomplishing this result and to avoid short-circuiting the battery a resistance is inserted in the circuit in the intermediate positions. The operation of this charging switch is shown in Fig. 48. All charging switches on the switchboard are arranged in series so that any number may be cut in at the same time. The voltage of the generator is adjusted for the number of cells being charged. Terminals are provided for connecting in a portable voltmeter ammeter.

To provide for the possibility of the alternating current failing or a fuse opening in the motor end, a three-phase 220-volt relay is used, operated in parallel with the motor controlling the charging circuit. Whenever the power fails or a motor fuse opens up, this

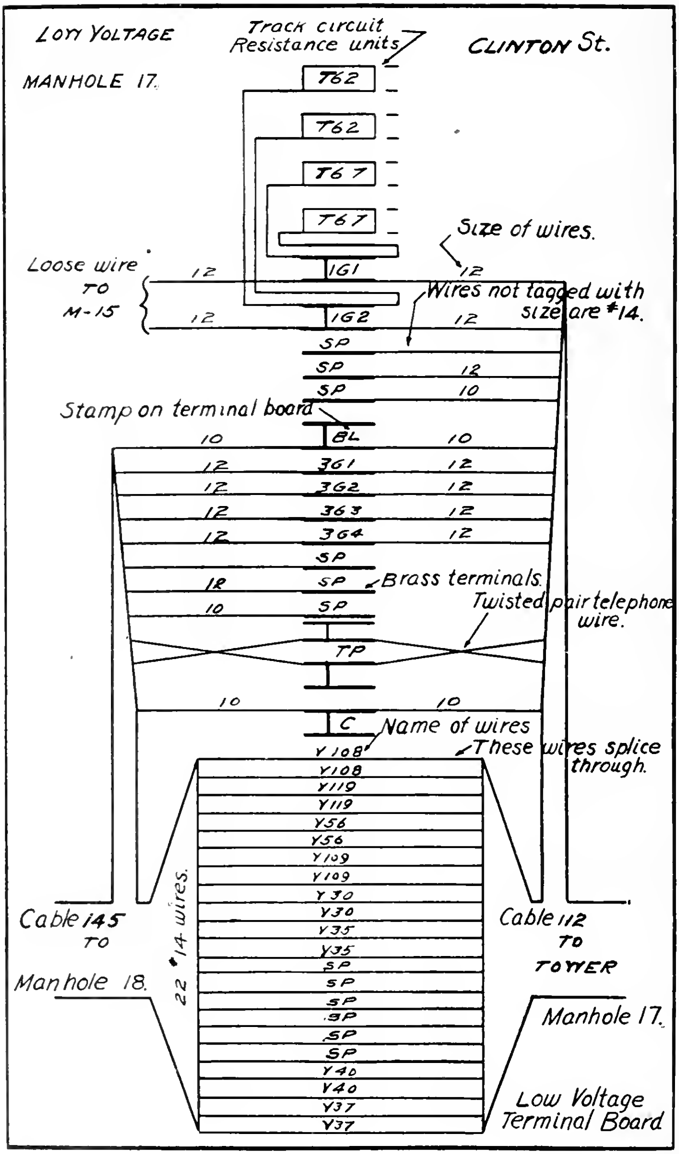


Fig. 45.—Terminal Board Plans.

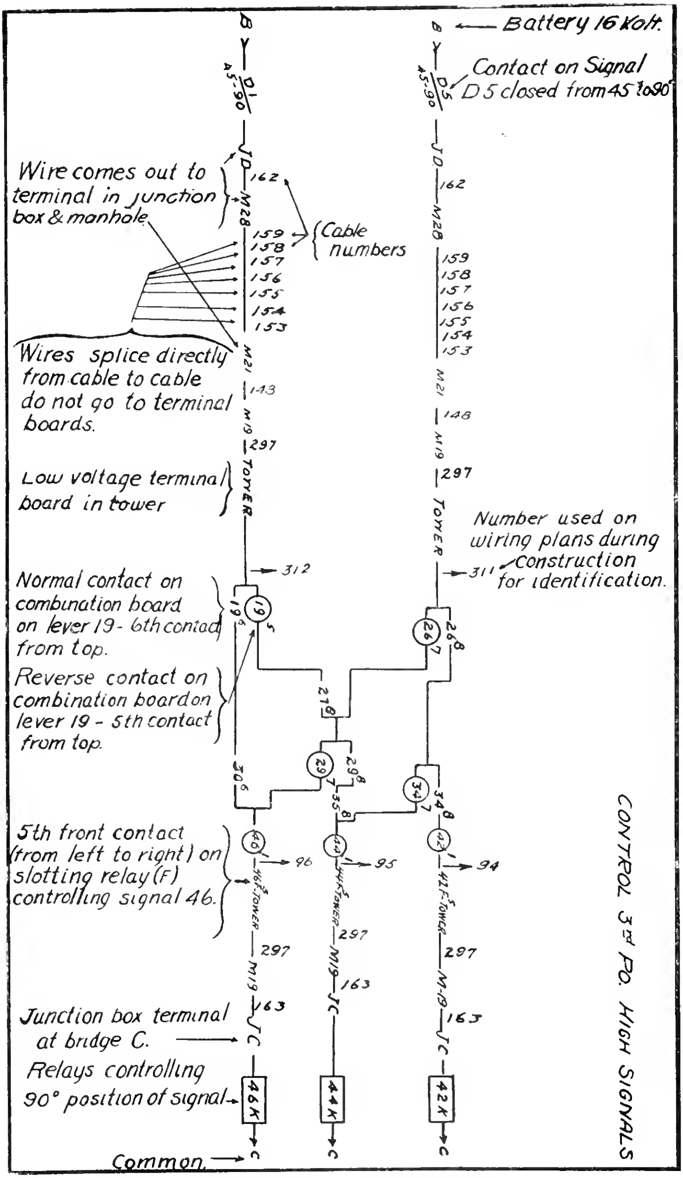

B
Battery 16 Volt.
D1
45-90
D5
45-90
Contact on Signal D 5 closed from 45 to 90°
JD
162
M28
Wire comes out to terminal in junction box & manhole
159
158
157
156
155
154
153
Cable numbers
Wires splice directly from cable to cable do not go to terminal boards.
M21
143
148
M19
297
TOWER
Low voltage terminal board in tower
Number used on wiring plans during construction for identification.
312
311
Normal contact on combination board on lever 19 - 6th contact from top.
Reverse contact on combination board on lever 19 - 5th contact from top.
19
26
27
29
30
34
35
46
44
42
96
95
94
46F TOWER
44F TOWER
42F TOWER
5th front contact (from left to right) on slotting relay (F) controlling signal 46.
163
JC
Junction box terminal at bridge C.
Relays controlling 90° position of signal
46K
44K
42K
Common
C
CONTROL 3rd PO. HIGH SIGNALS

Fig. 46.—Circuit Book Sheet.

relay opens the charging circuit preventing discharge of the battery. If the power returns, after failing, the relay picks up again and restores the charging circuit. As it picks up before the motor has reached full speed, the battery current runs the generator end as a motor and aids in bringing the set up to speed without excessive current on the motor end. The relay will not operate with one of the A. C. wires open.

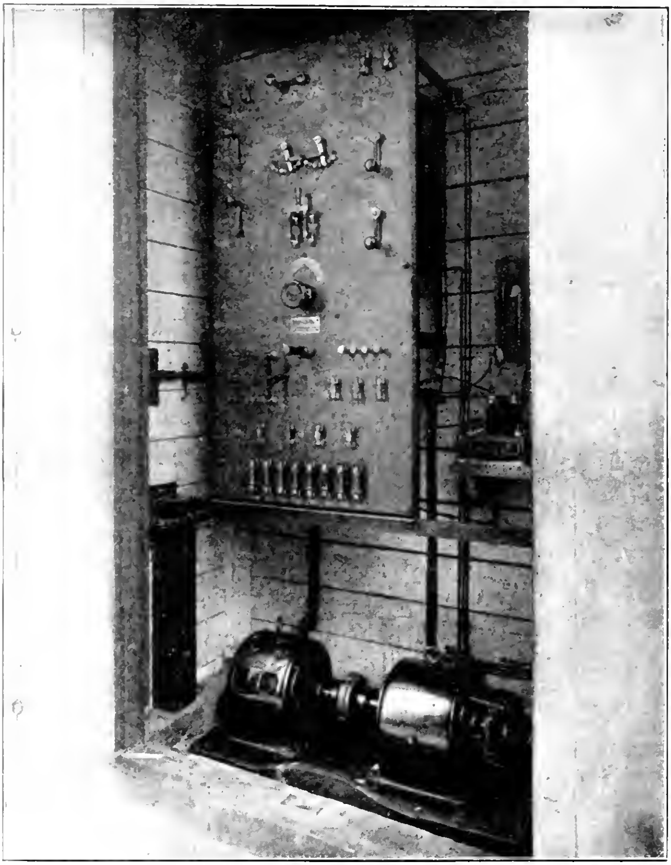


Fig. 47.—Bridge Powerhouse Switchboard and Motors.

POWER DISTRIBUTING SYSTEM.

Power for all purposes outside of Lake Street is taken from the power-house at 6,600 volts three-phase and distributed in the conduit system installed for this purpose and which is described elsewhere.

The power is transformed to 220-volt three-phase for power purposes and to 220 volt-110 volt single-phase for lighting purposes. Three-phase transformers are used for the power. All transformers are of the subway type. Both primary and secondary fuses are located in the manholes. Transformers located near each tower supply current for apparatus in the tower and also for the signal bridges which may be within a short distance. The remaining transformers are so located as to supply two or more outlying signal bridges.

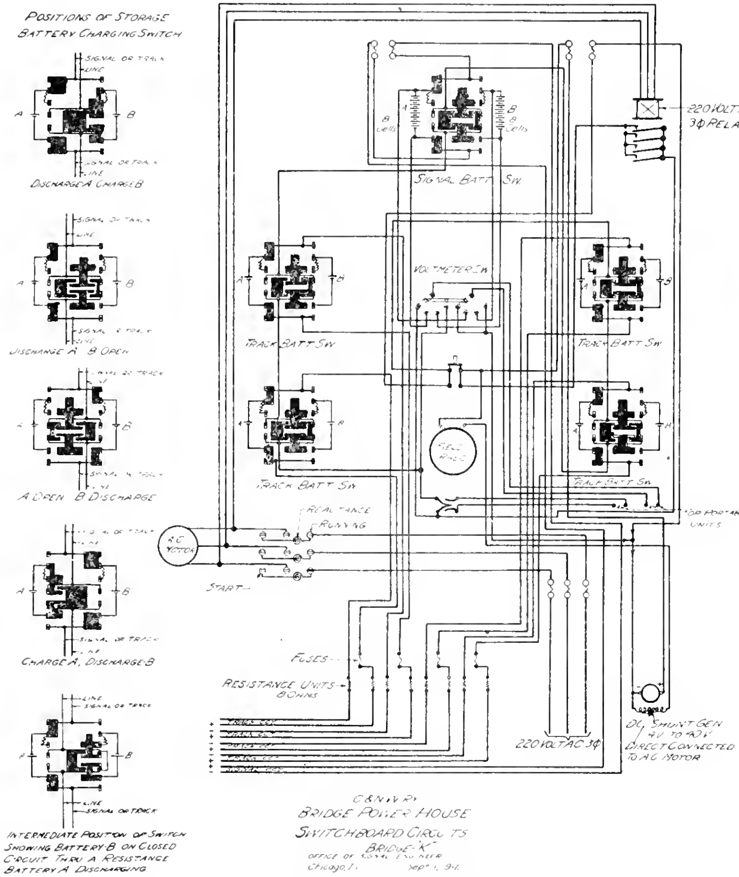


Fig. 48.—Bridge Powerhouse Switchboard Circuits.

The lighting transformers are arranged in pairs with secondaries in multiple so that there are two sources of power for each circuit, either transformer being able to carry the total load.

Motor-generator sets, as shown in Fig. 49, are provided in duplicate for each battery located in the towers. The motors are three-phase induction motors using a reactance coil for starting and taking power from the secondary mains of the transformers.

The generators are shunt wound with wide variation of voltage. A motor generator is running continuously connected in multiple with each battery, the motor generator taking most of the load and the batteries helping out on the peaks. Automatic underload circuit breakers are provided for opening the generator circuits in case of failure of the alternating current.

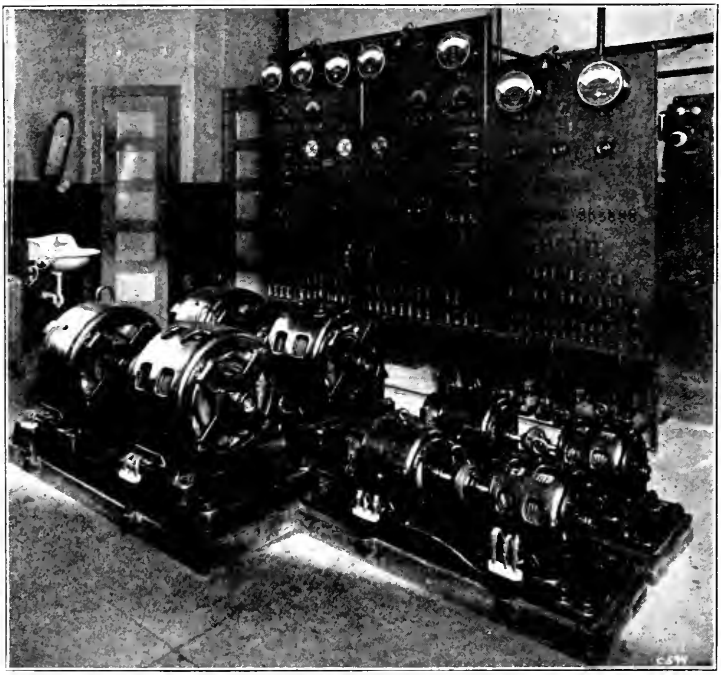


Fig. 49.—Motor-Generator Sets and Switchboard.

At the power-houses located at signal bridges, the motor generators, Fig. 47, are of the same type as those in the towers with a range of voltage from 4 to 40 and capable of charging one to sixteen cells of battery. An extra motor-generator set is kept on hand for emergency.

The current for the lever locks on the interlocking machines is supplied from a 220 to 55 volt transformer, connected normally to one leg of the power secondary, a switch providing emergency connection to the lighting secondary. In case the alternating current fails completely, another switch will connect the locks directly to the 20 volt battery, which is sufficient to operate the locks but not to light the lever lamps.

The illuminated track diagram is supplied with current from a 220 volt to 14, 12 and 10 volt transformer, connected in a manner similar to the 55 volt transformer to the power and lighting secondaries. The 14 volt tap is used in the daytime to give more brilliancy than is required at night, when the 12 or 10 volt tap is found sufficient. If the alternating current fails, the plants are operated without the diagrams.

Recording wattmeters have been installed in the power mains in the towers for the purpose of comparing consumption.

Unlike the other plants, Lake Street receives power from three single-phase transformers connected in delta, furnishing 220 volts, these transformers being located in the power-house. The electric lighting of this tower is normally on direct current from the power-house but may be put on alternating current.

A charging rheostat has been provided in this tower in addition to the motor-generator sets, so that the batteries may be charged direct from the direct-current mains in case of any failure to the alternating current. The same rheostat may be used to charge the 110 volt battery from the 220 volt mains and the 20 volt battery from the 110 volt mains.

In order to show the varied character of the voltages and currents, the following is a list with their uses in connection with the signaling:

6600 volts A. C.	Three-phase power transmission.
220 volts A. C.	Three-phase power secondaries.
220-110 volt A. C.	Three-wire tower lighting.
110 volt A. C.	Signal lighting.
55 volt A. C.	Locks on switch levers and lights on levers.
14-12-10 volt A. C.	Lights on illuminated diagrams.
220-110 volt D. C.	Three-wire tower lighting.
110 volt D. C.	On interlocking machine.
110 volt D. C.	On telautographs.
20 volts D. C.	Auxiliary circuits, emergency lever locks, telephone system, intercommunicating system.
16 volts D. C.	Automatic signal operation.
12 volts D. C.	Track circuit loop.
1 volt D. C.	Individual track circuits.

INSTALLATION.

To take care of the present needs and future requirements of power distribution and for signal, telephone, and telegraph purposes, as nearly as they could be estimated at the time, there was installed a main system of ducts, starting at the power-house with thirty-two and running north to a point near the junction of the north and west approaches, where a separation was made, and each approach was followed with two lines of eight ducts, one line on each side of the right-of-way as far as practical. One line on each approach is for power purposes and the other for signal, telegraph, and telephones. Separate manholes were built for each purpose, except that the telegraph and telephone ducts open into the same manholes. Where the ducts had to run together, three separate manholes were built, and the ducts assigned to one purpose ran through the manholes assigned to the other two purposes in a concrete block. 3-in. bituminized fibre conduit, laid in concrete, was used throughout. Across the subway bridges, and extending for 10 ft. on either side, a 4-in. iron pipe was run for each duct and the fibre duct was afterward put through this pipe. The manholes are built of brick with iron covers.

For the wires required for interlocking purposes, branch systems of conduits were installed, the same general type of construction as for the main line being used except that concrete junction boxes were used almost entirely instead of manholes, and 2-in. iron conduit was often used for short runs, where a larger size was not necessary.

Inasmuch as a large portion of the switches that were interlocking are on structural steel work, the ducts were often laid in the concrete protection of the floors, the concrete junction boxes were built as part of the floor, and the waterproofing was made continuous up to and around them.

Means of connecting the outside branch wires to those in junction boxes and manholes was provided for in the way of 2-in. ducts set in the walls, a sufficient number being installed for all possible requirements, the top end being threaded and capped, the cap being removed from those required for use and a split elbow bolted on.

Lauricated tubing was used exclusively as conduit for both loose wires and cables in the towers, and standard bushings and condulets were found that fulfilled all requirements for branching and at ends.

To protect connections between the junction boxes and manholes, and the switch movements and signals, which were always made with loose wires, wood trunking was used. This was constructed of 3 by 4 yellow pine having a groove 1¾ by 1½ in. in it, covered by a board 1¼ by 4 in. nailed on.

All rubber-covered wires were Okonite, the thickness of insulation complying with the Fire Underwriters' requirements. Where more than six wires were run in one duct, the wires were generally made into cables, covered with lead shield. For the intercommunication system, paper insulated wire in cables of the regular telephone type of construction was used. For power distributing purposes, cables were used made up of three No. 4 B. & S. gauge copper conductors insulated with cambric and covered with lead.

The cables for signal purposes are short for the most part and a great many splices were necessary. Most of these splices were rather difficult to make on account of being of the "T" variety, i. e., some of the wires of both cables were connected directly together, while other wires from each cable had to be carried out.

For distributing purposes in the junction boxes and manholes, distributing boards were used made of maple boiled in paraffine; the boards had rows of holes along each side and brass clips screwed in cross-wise. A wire is carried through a hole on one side of the board, and is soldered to the clip; its connecting wire is brought through the hole on the opposite side of the board and soldered to the same clip. The board is then stamped with the name or number of the wire just below the clip. By this means each wire connection can readily be found and there are no binding posts to get loose and cause poor connections.

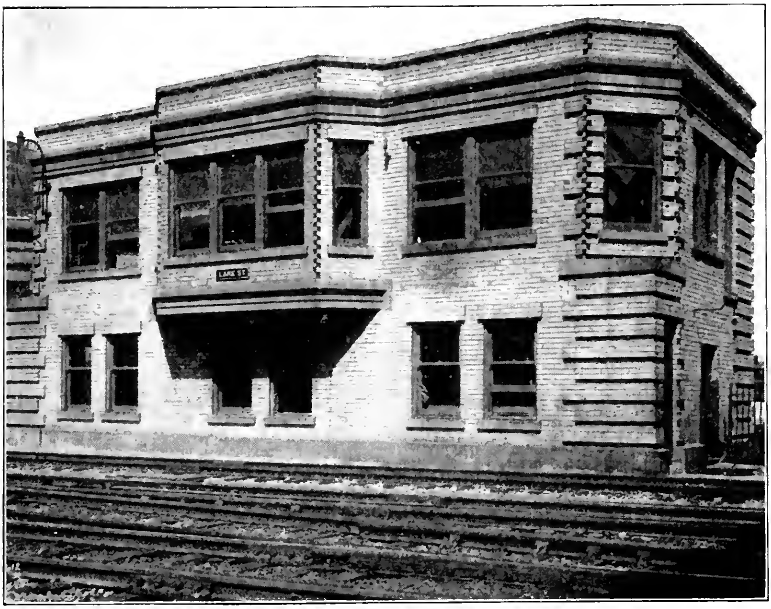


Fig. 50.—Lake Street Tower, Front View.

BUILDINGS.

The several illustrations clearly show the general appearance and arrangement of the interlocking towers.

In one of the illustrations of the Lake Street tower. Fig. 50, is shown a very long window on the right side of the upper floor, while the other illustration, Fig. 51, shows the relative height of the Lake

Street Elevated Railroad to the tower. In order that it might be possible for the director of the tower to see underneath the Lake Street structure toward the mail tracks, and the east end of the yard, it was necessary to install this window, a stairway leading to a well in front of the window being provided for the men wishing to make use of it. This interlocking tower is three stories high, as shown in the illustration, the lower story being entered from the street level and the second story from the track level. In Fig. 52 is shown the arrangement of the three floors.

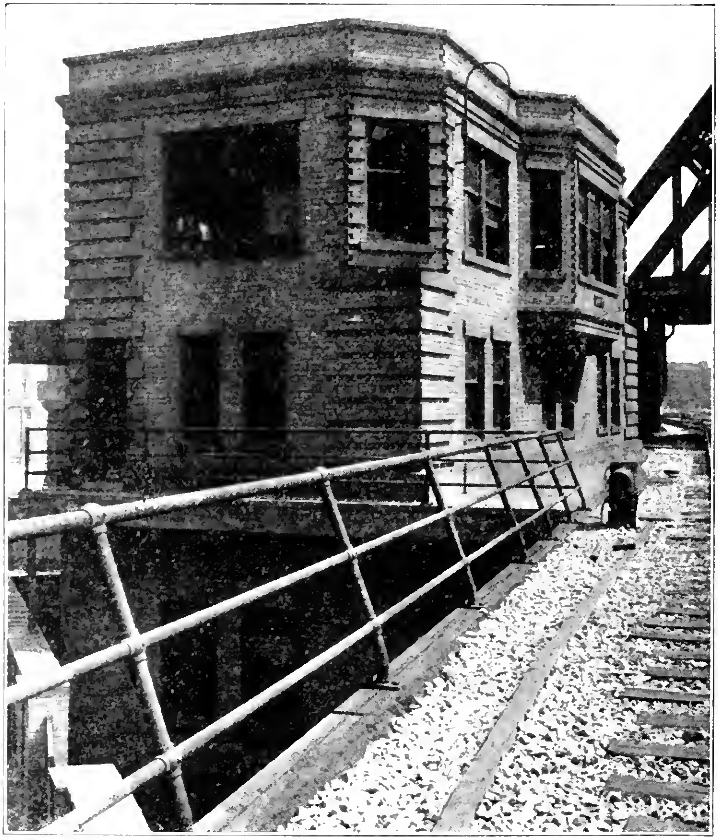


Fig. 51.—Lake Street Tower, North End View.

The interlocking towers at Clinton and Division Streets are equipped with relay cases similar to that at Lake Street, shown in Fig. 53 as to the face, and Fig. 54 as to the back. Inasmuch as open relays were used for convenience of maintenance, glazed doors were provided on these cases to protect the relays from dust and dirt. On the right side of Fig. 53 is shown a ladder running on a rail at the top, which is provided in order that the upper relays may readily be reached.

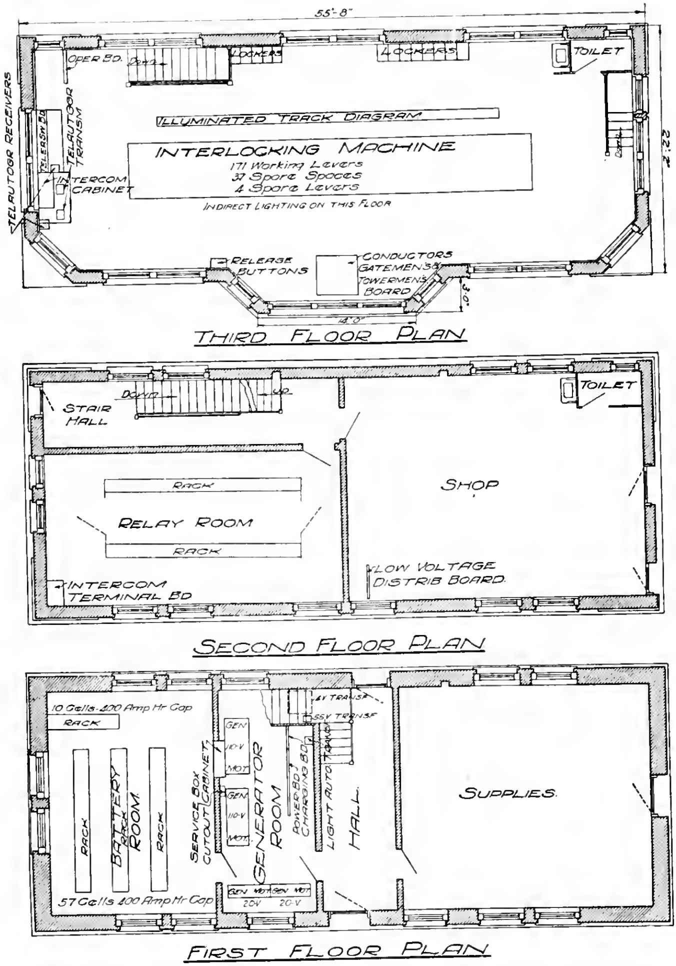


Fig. 52.—Lake Street Tower Plans.

In Fig. 54 is shown very clearly the manner of installing conduits, wires, and field terminal boards. The conduits and cables containing the wires from the outside do not show, as they come through the floor and are hid by the terminal boards and wires which run horizontally.

In Fig. 55 is shown the reinforced concrete battery shelves. These were used in Lake and Clinton Street towers. In order to protect against the effect of acid on the reinforcement, these shelves were thoroughly coated with an acid-proof paint. This illustration also shows the arrangement of storage batteries and the manner of connecting them.

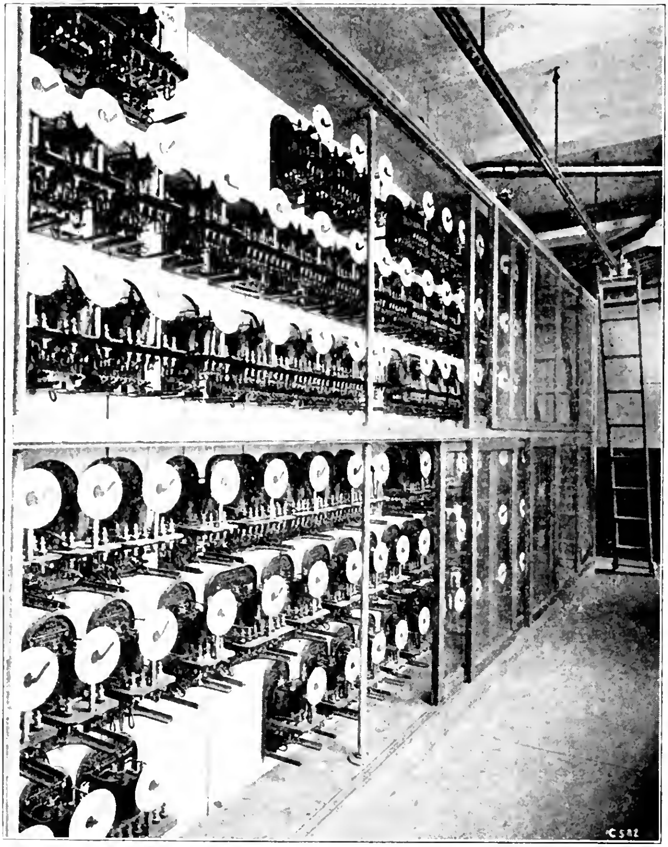


Fig. 53.—Relay Cases, Front View.

Clinton Street tower, Fig. 56, is mounted on top of a peculiarly shaped bridge abutment, and this accounts for the shape of the tower as shown in Fig. 57. The space on top of this abutment was not quite sufficient for the tower, and in order to make enough room, beams were put in, in the form of cantilevers, and on these the building was constructed. Even with this arrangement the room provided was hardly sufficient and illustrations, especially Fig. 49, of the room in which the switchboard and motor generators are located, will show how congested is the arrangement.

Carpenter Street tower, Figs. 58 and 59, is small and congested, and the general construction was as cheap as it was possible to make it and comply with the city requirements, for the reason that it was considered that this tower and plant would be temporary.

At Division Street, Figs. 60 and 61, there was plenty of room for the building and a better arrangement was made.

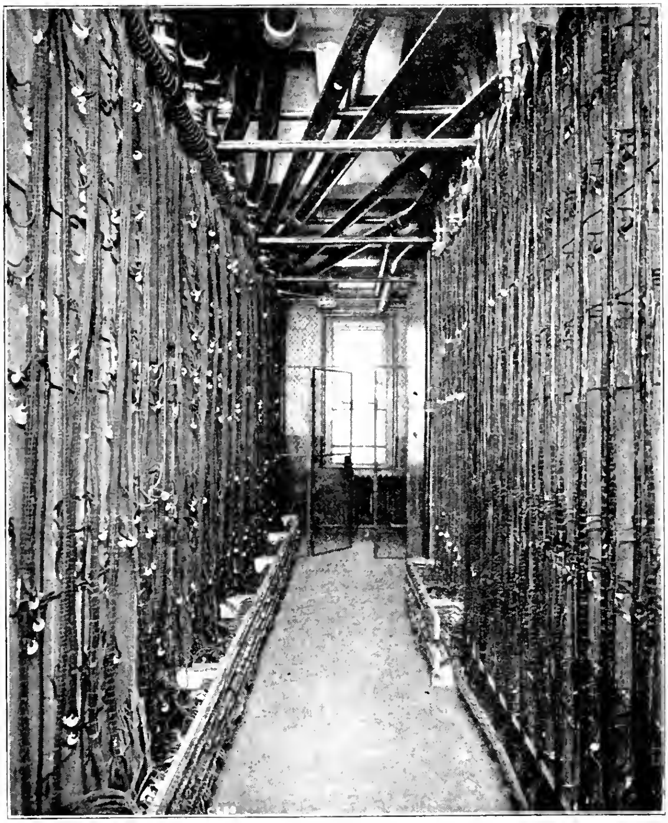


Fig. 54.—Rear View of Relay Cases.

The Noble Street tower, Figs. 62 and 63, is another small one, due to the fact that the location selected was the only feasible one, and in order to take care of the tracks on the old line temporarily there was very little room in which to locate the tower. The illustration does not show clearly that this is a three-story tower, but inasmuch as the grade on the old line is sufficiently low, one can enter directly from the low track lever into the basement.

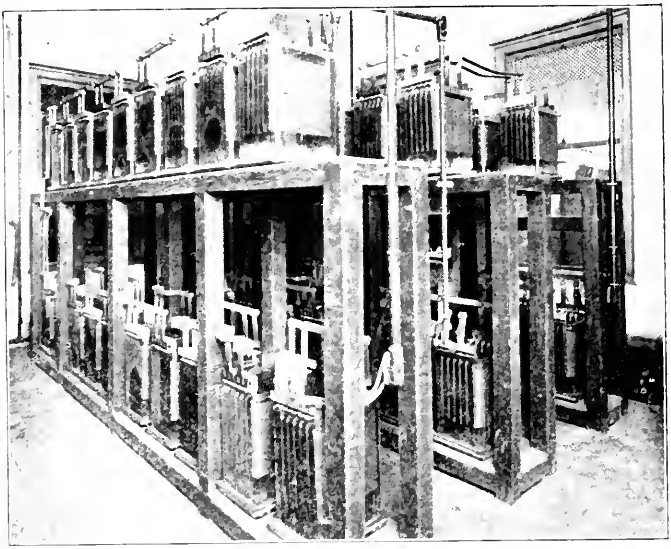


Fig. 55.—Battery Shelves, Lake Street Tower.

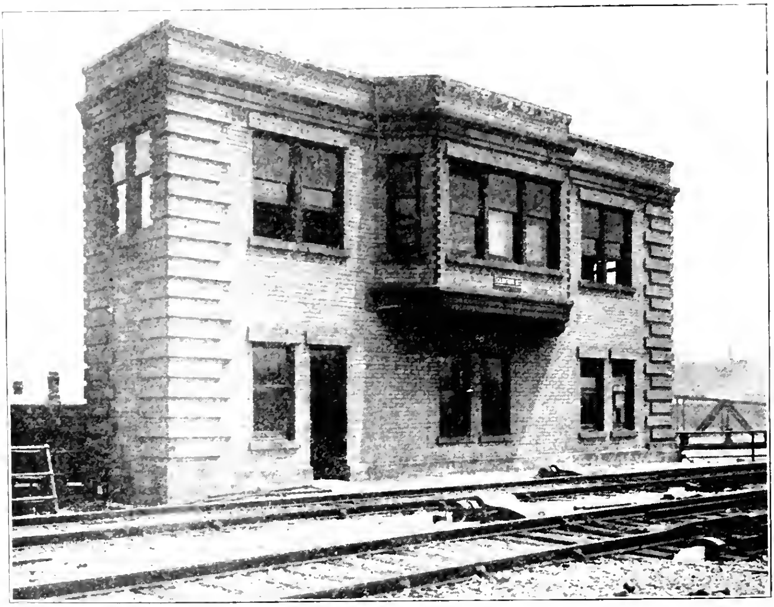
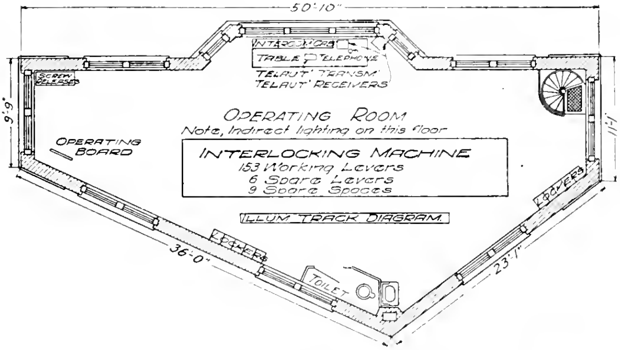
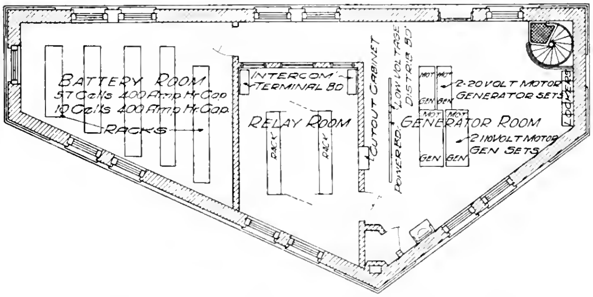


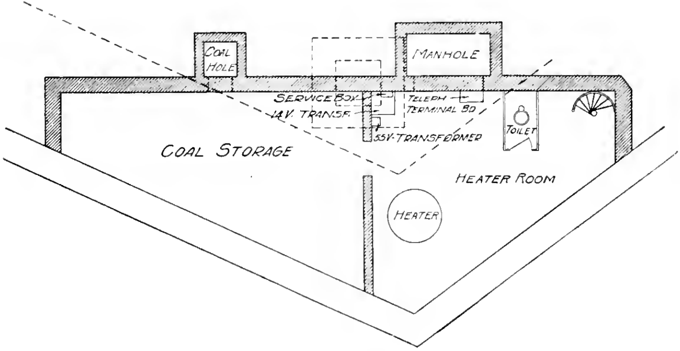
Fig. 56.—Clinton Street Tower.



SECOND FLOOR PLAN



FIRST FLOOR PLAN



BASEMENT PLAN

Fig. 57.—Clinton Street Tower Plans.

The heating of all towers is by steam, Lake Street tower being heated directly from the power-plant, while the others have their individual heating units.

The lighting is quite clearly shown in some of the illustrations. That in the operating room is indirect lighting which has proven very satisfactory. For other purposes direct lighting was used.

Figs. 64 and 47 show a bridge power-house as installed at each of the outlying signal bridges, there being eight of these. In one section of this house are the storage batteries, as shown in Fig. 64, there being a sufficient number of separate batteries in duplicate for signal and track purposes. The other section of the house is divided into two parts, one side containing the motor generator and switchboard, as shown in Fig. 47, while the other side contains the relays. Fig. 64 shows the method of construction of the doors to these houses in order to protect against dust and dirt, the inner door being fastened to the outer one and supported by bolts, while between the two doors are springs to insure that the inner door makes close contact against its bearings.

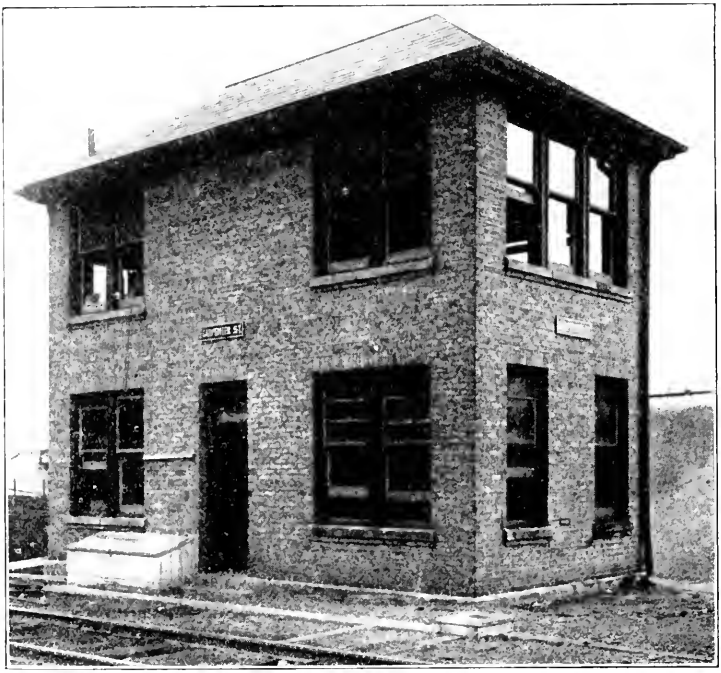


Fig. 58.—Carpenter Street Tower.

The doors on the other two portions of this house facing inward

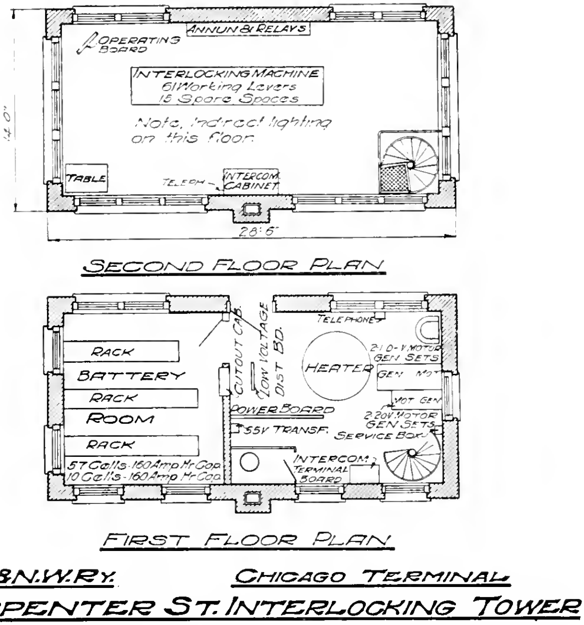


Fig. 59.—Carpenter Street Tower Plans.

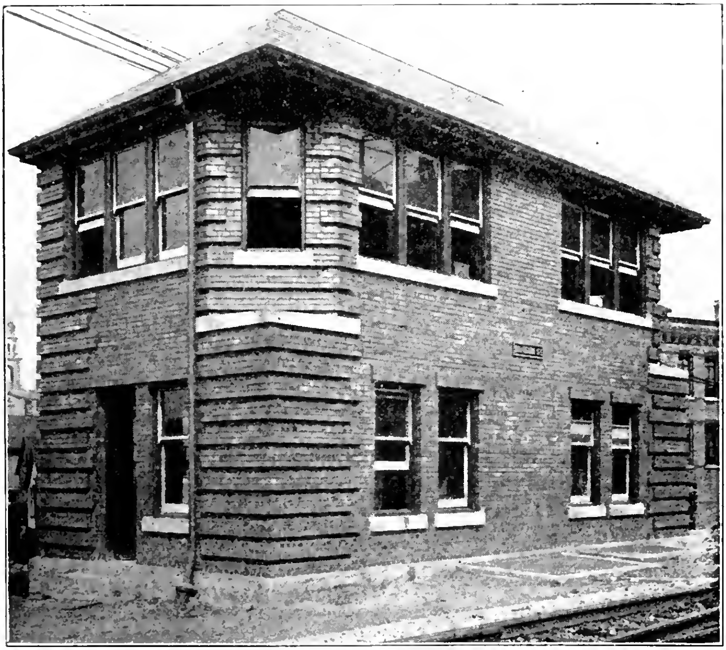


Fig. 60.—Division Street Tower.

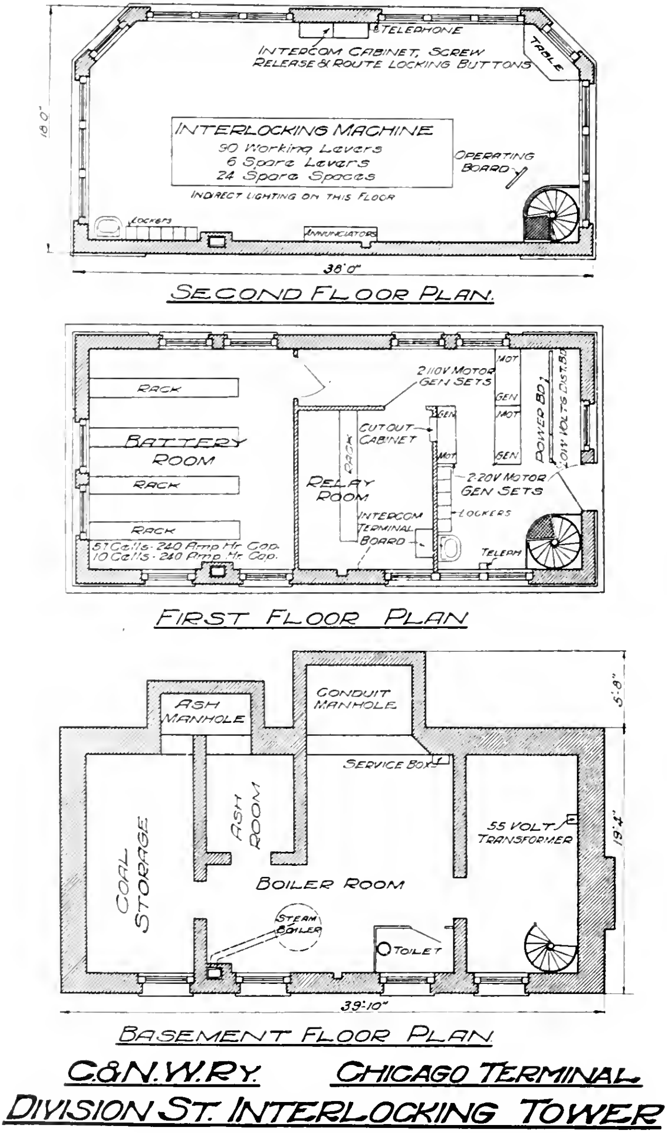


Fig. 61.—Division Street Tower Plan.

when opened come very close together, and by opening and fastening them together will provide a very good protection for the repairman while working during storms and cold weather.

DISCUSSION.

W. C. Armstrong, M. W. S. E. (Chairman): Mr. Peabody has given us a very clear idea of the complexity of this plant, and a proof of its efficiency is the fact that it has been working without any hitch whatever since it was first put in operation. It is seldom that a large plant of this kind is put into operation at once without more or less failures and more or less indication of how it might have been improved. But I can testify to the fact that everything has been working very smoothly, and while I am not an expert in signaling, I have talked with a number of the enginemen and trainmen who use it constantly and they have said that it is one of the simplest plants of any they have ever had to do with, which testifies to its efficiency.

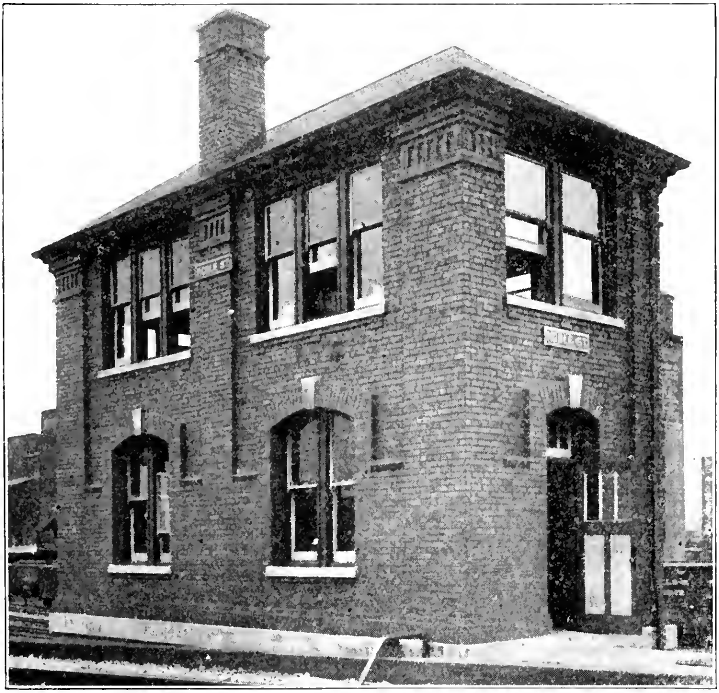


Fig. 62.—Noble Street Tower.

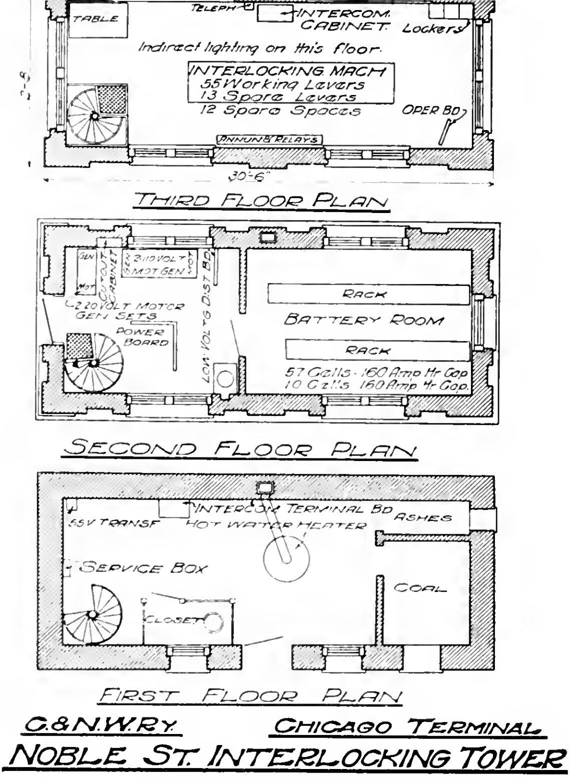


Fig. 63.—Noble Street Tower Plan.

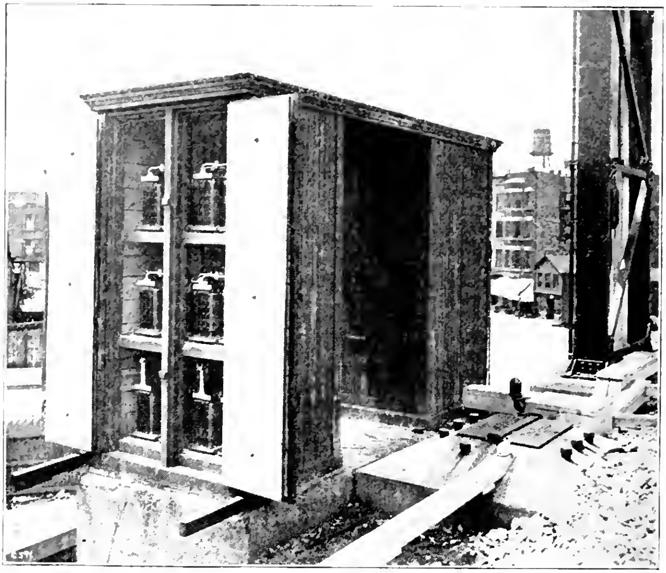


Fig. 64.—Bridge Powerhouse Batteries.

C. B. Lewis, ASSOC. W. S. E.: I would like to ask if there are any figures available on the number of lever movements in an average day.

Mr. Peabody: No, there are not at the present time. We have not made a count as yet, though we intend to do so shortly. We have a record of the train movements, but I have not that at hand.

Mr. Armstrong: There are about 330 trains per day, not counting the light engine movements and back-up movements.

Mr. Lewis: Are the outgoing trains backed in by their own engines, and the arriving trains pulled out by the switchers?

Mr. Peabody: The arriving through-trains are pulled out by switchers. The arriving suburban-trains back out by their own engines. All of the outgoing trains are backed in by their own engines except a few of the through trains, which are brought in early and are backed in by the switch engines and then their engines come in afterwards.

S. G. Neiler: In giving the various voltages used in the towers, Mr. Peabody mentioned one volt. I would like to know from what service current is furnished at that voltage and for what it is used.

Mr. Peabody: I do not know whether that was very clearly brought out or not. Tracks are divided by means of insulations into sections of varying length from 90 ft. up, and it is to these sections that we supply one volt current. The resistance between the two rails is not very great, depending on the ties and the ground condition. Of course when the ground is damp in wet weather, and so forth, the resistance is very little, and therefore it is necessary to use a very low voltage.

Mr. Neiler: Do you get the voltage from a storage battery?

Mr. Peabody: We get that from the storage battery; yes.

Mr. Neiler: What is the object, Mr. Peabody, in using a three-phase transformer in the manholes instead of three single-phase transformers? Was it on account of restricted space?

Mr. Peabody: Well, our restricted space did materially have a bearing on it.

G. T. Seely, M. W. S. E.: I would like to ask as to the relative capacity in trains per hour of the new installation with the six-track throat, as compared with the old tracks laid out with the two-track throat. It is not exactly in line with the paper of the evening, but I would like to know about it.

Mr. Peabody: That would be, I believe, impossible to answer truly. It is a matter of opinion. The old lay-out, the two-track throat, with its drawbridge at the mouth, depended almost entirely on the ability of the men to solve problems quickly, while with our new one, with the six-track throat, the capacity depends more on the rapidity with which we can load and unload trains than on anything else. I do not believe that it is possible to figure that out. It will be a case of experience.

Mr. Seely: My idea in asking the question was this: That the chief reason for building this station was to get an increase in capacity. About $20,000,000, I understand, has been spent for it, and I am wondering what is the increase in capacity.

Mr. Peabody: There is no doubt that we have doubled the capacity in our new station with the same number of station tracks. In addition we have absolute reliability of operation. In the old terminal we were subject to aggravating delays at all times on account of the drawbridge.

Mr. Armstrong: I think there is no doubt but that the capacity of the new station is fixed more by the capacity of the station tracks and the facility for loading and unloading passengers than it is by the number of tracks in the throat. Six tracks in the throat of the yard will evidently take care of all the main movements as fast as the trains can be loaded or unloaded.

Mr. Lewis: Is it a fact that there is an intention to operate other tracks at the second level at some future time?

Mr. Armstrong: I do not think there have been any plans for operating on more than one level; in fact, our design would have to be materially changed in order to operate on two levels, and it would be impracticable to make such changes. Our track space in the station yard is very nearly double what it was in the old station, although there are the same number of tracks.

Mr. Lewis: Is that on account of the increased length of tracks?

Chairman Armstrong: Yes, on account of the increased length of tracks.

Mr. Peabody: I would say in that connection that immediately on getting into the new station the length of all through trains was increased and the number of trains was added to, so that really a direct comparison as to the number of trains we are handling is not exactly fair, because we are handling a great many more coaches per train, on the average, than we were before.

Mr. J. S. Robinson: I would like to ask the time that one train can safely follow another on the same track.

Mr. Peabody: That can be given in feet more nearly than in minutes. The trains can be safely operated at 250 ft. apart and could get a clear signal at that distance apart. They could in some cases come from two separate tracks, I should say offhand, on 300 ft. apart, the second one getting a clear signal so that it would come into a converging track without delay.

Mr. Seely: How many trains an hour are you handling during the heaviest hour?

Mr. Peabody: I really do not know what is the number at the present time. Of course, by far the heaviest hour is from 7:30 a. m. to 8:30 a. m. and from 5:00 p. m. to 6:30 p. m.

W. D. Jones, M. W. S. E.: I would ask if the Galena Division uses the east tracks in the morning. I notice two trains are put on the same track and the others are empty.

Mr. Peabody: We have that arrangement so that we can put two trains on a track, if necessary, but so far we have had very little use for that. There is one track upon which two trains are scheduled at the present time every evening about 5:15. In the normal method of tracking the trains for the Galena Division suburban trains, we use the west three tracks. The next seven tracks are given over to the through trains,—the west of those seven to the Galena Division and the east of them to the Wisconsin and Milwaukee Divisions, as far as possible,—but they do not stick very closely to east and west tracks for the through trains. Then the last six tracks,—the east six,—are used for the Milwaukee and Wisconsin Divisions suburban tracks. However, they are apt to track trains on any track that is most convenient.

Mr. Lewis: Does not that cause quite a little difficulty in getting a notice board set up at the gate entrance?

Mr. Peabody: That is all prearranged. When I say they track these trains whichever way is found most convenient, the trains are back-up trains and are scheduled the same as through trains. Each train is scheduled from the coach yard and has an individual number from that point. For instance, a Milwaukee Division suburban coach train will leave the Erie Street yard at a certain time, pass through the Erie Street interlocking plant at a certain time, into the Clinton Street plant at a certain time, and pass the Lake Street tower. Those tables are made up just exactly the same as the timetable is made up, so that everybody knows what track it will leave from and what time it will be in there to leave. The inbound trains are also, if on time, scheduled on to a certain track. Of course, if they are late we have to change the arrangement. That is where the telautograph scheme comes in, on the inbound trains, when the trackage is changed.

Mr. Lewis: I understood from your earlier statement that a train might leave on one track today and on another tomorrow.

Mr. Peabody: That was a misunderstanding or a misstatement. We do not change the trackage from day to day. This may be done with each new time-table but not otherwise. If you have been in the station very much you have probably noticed that sometimes they set up the gate indicator, it may be an hour or two before the train is backed into the station during the middle of the day. Frequently after a train leaves, the indicator for the next train is put up, and that train may not be scheduled to leave for three or four hours.

C. R. Dart, M. W. S. E.: How are those gate indicators operated?

Mr. Peabody: The indicators are operated mechanically by means of a fiber plate with holes punched in it, a bar fitting into each hole for each station. The names of the stations are on square blocks, three sides being used for names; the other side is blank, and it simply depends on whether one of the bars that operates that block is in a hole or an elevation, as to the position it assumes. The whole is mechanical,—it is operated by a man with a lever, from a ladder.

ELECTRICAL AND MECHANICAL EQUIPMENT.

S. G. NEILER.*

Presented before the Electrical Section, W. S. E., and the Chicago Section A. I. E. E., at a joint meeting, September 27, 1911.

The Chicago & North Western Railway Terminal at Chicago does not differ in any marked degree from other recent large terminals. It has its own central power-plant the same as the Pennsylvania Railway Company has provided for its New York and Washington terminals.

The Chicago & North Western Railway Company's old power plant at the Wells Street station was inadequate and in fact had been out of commission for some time, service being furnished from an electrical supply company. Upon the railway company's decision to build an entirely new plant, the first question to be considered was: Should the plant be located and designed with reference to possible future electrification? The recommendation of the consulting engineers, that the Terminal plant be separate and distinct and in fact stand by itself, was approved by the railway officials. The next point was to settle upon the location, and of the three sites proposed, the one selected possessed many advantages over the others. The short time the plant has been in service has demonstratd conclusively the economical value of a plant of this character for meeting the service requirements of the Terminal, and the results obtained amply justify its installation, and more particularly the selection of the apparatus and the general scheme of distribution of both heat and electricity.

GENERAL CONSIDERATIONS.

The problem was primarily to provide light, heat, and ventilation for the station building and the undertrack portions; following this, to light the train sheds, yards, streets and subways; to properly arrange for the heating of the trains while standing on tracks and to provide compressed air for charging train reservoirs for air brakes, together with other miscellaneous detail matters incident to the uses of a building of this character.

For a structure of this kind, the questions of heating, ventilation, and lighting were extremely vital ones and necessarily required careful study. The customary preliminary details were worked out and after the various schemes were in the process of development, prominent undertakings throughout the country were visited.

In the design of a steam power plant of the mixed-service character of this, the heating system was one of the first points to be given consideration following the location of the power-house. As there were conditions which rendered it impossible or inadvisable to

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*Pierce, Richardson & Neiler, Consulting Engineers, Chicago.

obtain condensing water from the river, the majority of the apparatus in the power-plant must be run non-condensing. Exhaust steam in considerable quantity was therefore available, and it was decided to use this for heating purposes by means of a vacuum system. The selection of continuous-current electrical apparatus rather than of an alternating current was governed primarily by the large number of horse power of variable-speed motors required for driving ventilating fans and, further, due to the fact that its manipulation was less complicated. Its adoption saved approximately $20,000 of initial investment.

Relatively high tension was to be avoided in the transmission as the cables had to be carried in the train-shed structure, and as the advantage of the A. C. service would be in the transmission from the power-house to the Terminal building principally, the only thing to do was to adopt continuous current throughout. This, as it has turned out, was a wise selection in many ways, as certain plans which the railway company had in contemplation were abandoned, as in one instance this called for the outbaggage elevators to be changed from hydraulic to electric.

The system being intended mainly for work in a very limited area, it is a direct-current proposition with balancer sets to take care of the three-wire distribution. The yards, freight houses, etc., are some considerable distance away, and for serving these points alternating-current motor-generator sets were installed. This is a complete reversal of every-day precedents brought about by the unusual conditions of distribution.

The system of lighting was early determined upon. After a very exhaustive investigation of the various types of lighting units available, the Tungsten lamp was adopted and the results obtained are very gratifying, not only from the maintenance and economical points alone, but on account of the lighting effects which this unit permits.

Economy of operation being one of the governing factors in all that was done, it dictated the installation of the hydraulic elevator where such could be used, and in consequence the thirteen elevators in the main building and at the south end of train sheds are of this type. The pumping machinery for these was placed in the basement of the station building, steam-actuated pumps were installed, and high-pressure steam transmitted from the powerhouse for this service.

MECHANICAL AND ELECTRICAL EQUIPMENT.

In an installation of this character, covering as it does so many and varied applications, there are numerous points which will be of interest to the engineering fraternity. While there is nothing in the nature of a radical departure from current practice, many new and novel schemes have been worked out in connection with both the electrical and mechanical work. The plant stands alone in its completeness, simplicity, economy, and reliability, among those most recently designed for any similar purpose. As brief a description as possible, consistent with clearness, is given of the various portions. The paper describes at considerable length, however, such of the details of construction and apparatus as the author believes will be of more particular interest to the members, and at the same time be more or less of a guide to those who may have similar work in charge, particularly as the data available in engineering literature are extremely meager.

The central power-plant is located north of the Terminal station and train sheds in the triangular block bounded by Lake Street, Clinton Street, and Milwaukee Avenue. The plant has been laid out with special reference to the unusual ground-plan conditions, and the space has been utilized to good advantage with the chimney stack occupying the apex of the triangle, the arrangement of machinery being such as to secure all necessary room for the desired purposes. Pressed brick along the inside walls, set off with green Rookwood tile wainscoting from the engine-room floor up to the window sills around the visitors' gallery in the engine-room and in the engineer's office, adds greatly to the appearance.

A view of the buildings, looking south from Milwaukee Avenue, is shown in Fig. 65.

In this plant is developed all energy for light, heat, and power service and in other ways to serve the varied requirements of the entire Terminal station, which includes the station building proper, the train sheds, and undertrack portion, together with the Lake Street interlocking tower. Machinery has been installed to furnish electricity for all interlocking towers and for lighting subways of the station approaches in the territory north of the power-house, and for yards and freight houses.

The Terminal station building is heated by exhaust steam from the power house, a relatively small amount of direct radiating surface being installed; the large public space on the ground floor and the Main Waiting Room on the track-level floor being heated and ventilated by the blast system. Other of the important public rooms are ventilated but are supplied with radiation as well, such as the Dining Room, Women's Room, Smoking Room, etc.

HEATING SYSTEM.

At the south end of the power-station in the machinery room is a 24 in. cast header, to which is connected one end of the 30 in. main exhaust header by 24 in. pipe, this connection being shown in the lower part of Fig. 66. From this 24 in. supply header two 14 in. pipes are run for transmitting exhaust from the power-house to the main building. These are carried in a runway above the train shed on the Clinton Street side; for the undertrack portion, two 10 in. pipes are run, one to care for the Post Office and the other for the remainder of the undertrack portion, these being connected to the power-house end of the 24 in. supply header. The two 10 in. pipes are cross-connected about midway of the run, and in turn connected through pressure-reducing valve to the high-pressure train-heating main and that for downspout heating. These connections afford ready means for equalizing and protection in case of a breakdown of the train-heating pipe. The method of caring for expansion of the 14 in. heating transmission pipes, and the manner in which they rise to the runway above the train sheds, is shown in Plate XVIII. A cross-section of the runway is shown in Fig. 67, upper right hand corner. At the station end the two 14 in. mains connect to a header, from which all heating supply mains for the building are run. In the connections between the pipe runway and this header there have been placed Wainwright corrugated, re-

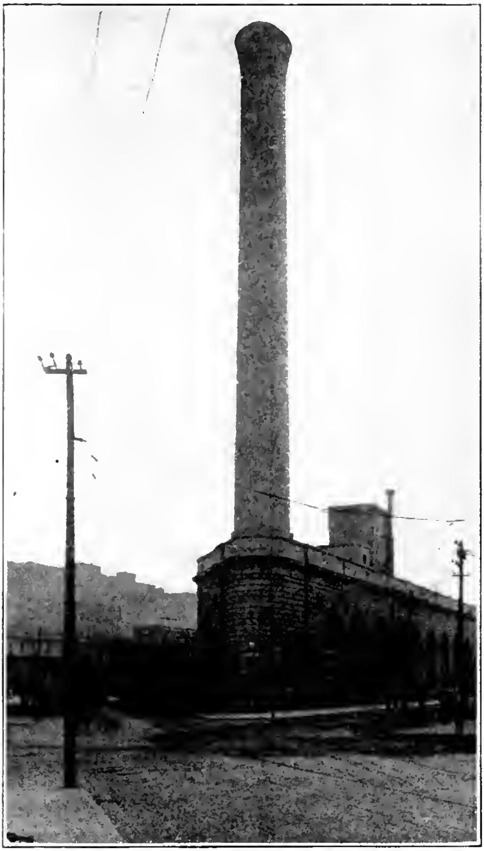


Fig. 65. Power Station.

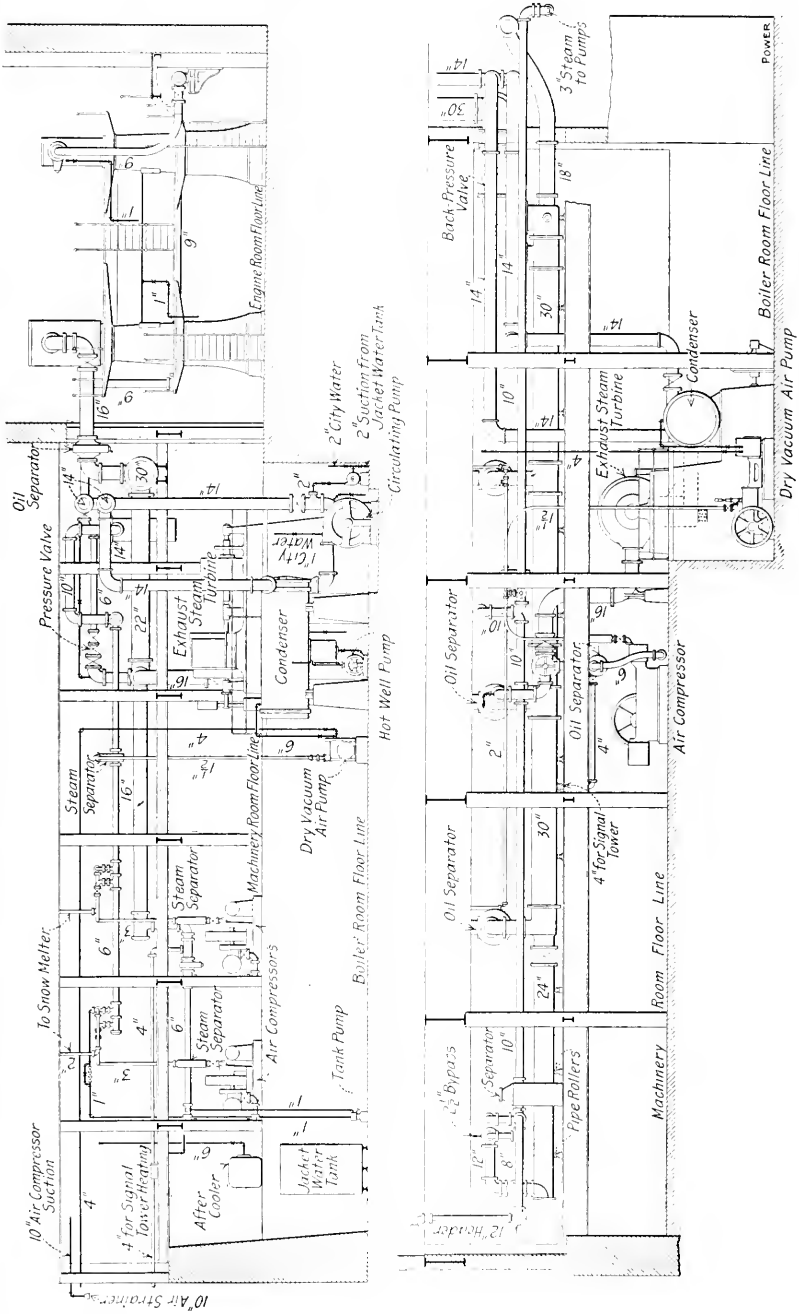


Fig. 66. Plan and Elevation—Machinery Room.

inforced, copper joints to relieve the fittings of any strains due to expansion.

The heating arrangements in the main building are extremely simple; the overhead system of piping is provided for direct radiation, while the blast coils in the basement are fed directly from a central distributing header. The direct and the indirect, each has its own set of vacuum pumps to remove the condensation and deliver same into a common receiving tank located in the sub-basement. This tank is provided with a special float valve which governs the steam admission to return pump, which delivers the hot returns back to the feed water heater in the power-house.

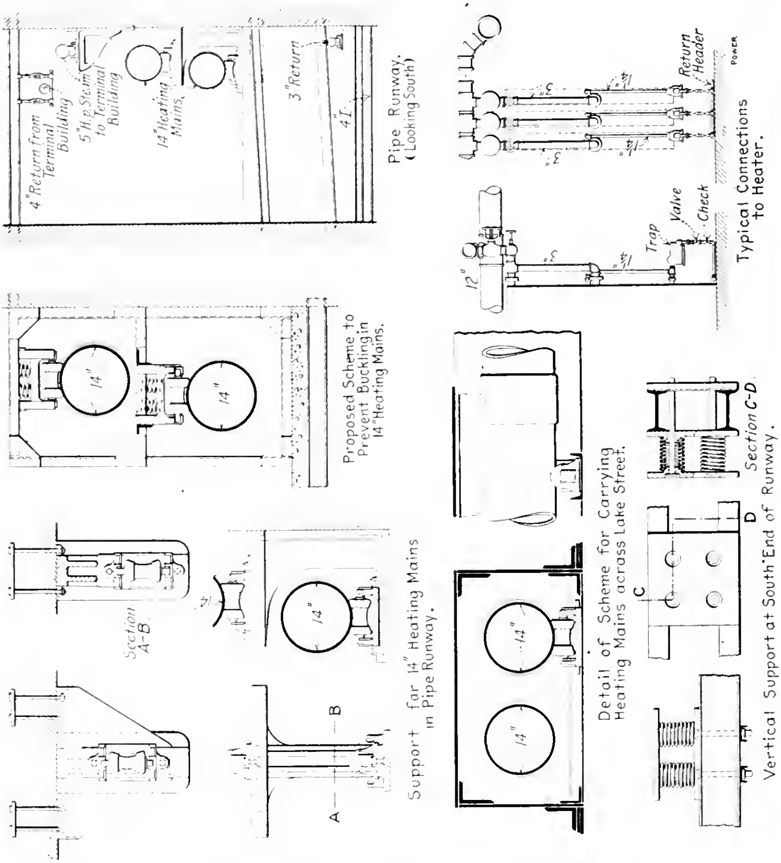

4" Return from Terminal Building
5" H.p. Steam to Terminal Building
14" Heating Mains
3" Return
4"
Pipe Runway. (Looking South)
Return Header
Power
3"
1½"
Typical Connections to Heater.
Valve
Check
Trap
12"
Proposed Scheme to Prevent Buckling in 14" Heating Mains.
14"
14"
Section A-B
1½"
14"
A
B
Support for 14" Heating Mains in Pipe Runway.
14"
14"
Detail of Scheme for Carrying Heating Mains across Lake Street.
Section C-D
C
D
Vertical Support at South End of Runway.

Fig. 67. Details of Steam Distribution.

In the undertrack portion, the steam-supply pipes are all carried through or suspended from the track structures. Branches drop down to the radiators with the vacuum returns run below the floor line. In the Suburban Concourse and in the Emigrants' Quarters, tunnels are provided in which the steam-supply and return pipes are run. This arrangement was necessary to permit of setting radiators in the middle of the room, for the Emigrants' Quarters, and to keep vertical pipes out of the concourse. The tunnel in the Suburban Concourse is designed with entrance doors at either end and with partitions, as it is used for an air duct for supplying ventilation to the Post Office, and in this duct the supply and return mains are carried.

A total of but 31,800 sq. ft. of direct radiation has been installed in the main building, this being placed principally in the offices on the third floor; in the Women's Room, Dining Room, and Annex to Main Waiting Room on the track level floor, and in the Lunch Room and Baggage Room, on the first floor. Additional radiation has been installed in the public space just inside of the entrance from the Madison Street vestibule, as well as that on Canal Street, the particular object in this being to care for such cold air as will naturally tend to rush into the vestibules and the public space when the outside street vestibule doors are open, as the public pass in and out of the station. Radiation placed as this is will prevent drafts of cold air from coming into the main public space; likewise radiation has been placed in the Main Concourse next to the gates leading to the train sheds so as to temper this cold air as much as possible; for similar purposes radiation has been placed near the east and west entrances of the Suburban Concourse in the undertrack portion north of Washington Street. The Main Train Concourse has sufficient direct radiation to maintain a temperature of about 55 deg. F. with an outside temperature of minus 10 deg. F. As the train sheds being low protect part of the concourse on the north side, the radiation placed on the floor is located at the gates for the special purpose as already mentioned. On the track side, nearly all of the north end of this concourse is glass, and being exposed to the north, the only feasible means of properly heating the space was to place radiation immediately beneath these windows; for this purpose the architects provided a ledge of sufficient width to support the radiators.

The entire heating system throughout is that known as a vacuum system, this permitting the utilization of exhaust steam from the engines and other steam-actuated apparatus that may be necessary for heating purposes. The surplus exhaust steam is used in a low pressure steam turbine, a description of this being given later. For draining of the blast heating coils, a Crescent trap was installed in connection with each section. The delivery end of these traps for each unit is connected to a main, carried back to the suction of the vacuum pumps which are provided especially for this portion of the installation.

In the undertrack portion, all occupied spaces are heated and ventilated. Direct radiation has been installed to the extent of 11,500 sq. ft., exclusive of the Post Office, which contains 3,700 sq. ft.

It was considered of sufficient importance to provide direct radiation at the power-house and approximately 850 sq. ft. was there installed. The Lake Street interlocking tower is provided with 1,350 sq. ft. of radiation.

All direct radiation, where possible, was installed beneath windows; in special cases, such as in the Dining Room and in the Annex to Main Waiting Room, the radiators were recessed and covered with a massive solid bronze grille. In the skylights throughout the main building and on the walls of the Post Office, wall coils were used, these being held in place by a specially designed support provided with rollers for expansion. The extent to which this wall radiation has been used, and the manner in which its support and expansion has been cared for, have led to its adoption quite universally in the last year and a half.

The Terminal proper, extending from Madison Street to Milwaukee Avenue, being divided by the east and west streets into practically four sections, it was necessary to treat each block substantially as a separate building insofar as the return end of the heating system is concerned, for there were conditions which prevented an underground connecting tunnel. Each block therefore has its own duplicate set of vacuum pumps. These, however, deliver into a common return, running back to the power-house, excepting that the main Terminal station building is treated independently and has its own return. Some of the blocks are further divided by driveways, etc., which necessitated more vacuum return centers as the condensation could not be collected without sinking returns below the driveways, which would call for the pumps themselves to be set low. This was to be avoided and as no additional complication was involved, the number of vacuum return centers was increased. In the block between Washington and Randolph streets, the Post Office has its own vacuum plant, to which, however, is connected the returns from the Suburban Concourse, while all of that portion north of this concourse is cared for by separate pumps. The block north of Randolph Street, running to Lake Street, is sub-divided, it being impossible to connect the two sections at the north and south sides of the driveway for outbound baggage. Vacuum pumps in the power-house care for such radiation as is placed in the engine room and also for the Lake Street interlocking tower in the same block. The exhaust from the engines and other steam-actuated apparatus in the power-house is utilized for heating purposes and is supplemented at the station building by the exhaust from elevator pumping machinery and pumps used at this point in connection with the heating system. Cross connections are made to the high-pressure piping so as to supply any deficiency if conditions ever arise where an extra supply of steam is necessary. During the summer months, the exhaust from the elevator pumps is utilized for the heating of water for the kitchen, toilets, refrigerating apparatus, etc. The excess from the elevator pumps during the summer months, which would otherwise go to atmosphere, is delivered back to the power-house; in the winter time it is used in the heating system.

Since operation began it has been found that there has been more exhaust steam than is sufficient to meet the requirements of the refrigerating plant, approximately some 500 lbs., of steam could readily be used at the power-house in the low-pressure steam-turbine, and as there is some 1,500 ft. of 14 in. pipe which can be used as a regenerator, or, more properly speaking, a storage tank, the valve at the station building end of one of the 14 in. mains was partly opened, while at the power-house end, the valve was opened wide. It was found that, with the elevator pumps 1,500 ft. away exhausting into the system at one end where steam was required for the heating of water for domestic purposes and for the refrigerating plant, approximately some 500 lbs. of steam per hour which would otherwise have been exhausted to the atmosphere, could be "stored" for the turbine use. This has worked out so well in practice that for economical reasons alone one of the vacuum pumps and one of the steam return pumps is kept in operation at the main building during the summer months, the vacuum pump discharging the condensation from the water heaters into the receiving tank, and the return pump delivering this condensation back to the feed water heater in the power-house, the pumps exhausting into the 14 in. main.

Some few years ago a system, original with the author, was designed, whereby the discharge from traps draining high-pressure mains could be cared for and saved without the necessity of running returns back to the central point, and by an independent pump delivering to the power-house receiver or feed water heater. The traps are arranged to discharge directly into the heating mains; the discharge being under pressure will flash into steam and thus permit of the major portion of it being used for heating. The water under the pressure of the heating system is cared for by the vacuum pumps the same as the condensation from any of the radiation. This system is used to drain the downspout heating mains. The train-shed roof and the track floor are drained by downspouts in the usual manner, but as the horizontal runs below the track floor are in many cases exposed to the weather, it was necessary to prevent possible freezing of these portions, especially as the flow would be sluggish during weather when there would be alternate freezing and thawing. As the track floor is drained directly into the piping below, steam for warming could not be discharged into the runs to keep them heated, as it would rise out of each drain and in cold weather cause considerable fog in the sheds. Numerous methods were discussed and each in turn dismissed as impractical until the one finally adopted was settled upon. This consists briefly of a 1 in. extra heavy pipe carried directly beneath the horizontal run of downspout piping, and held snugly to same by special clamped bands placed at intervals, the 1 in. pipe being bent where heavy cast-iron sewage-fittings were encountered. These pipes were drained back into traps, discharging into a main which ran north and south, and collected several of the cross discharge pipes, the traps in effect discharging directly into the system of heating mains as above described. A diagram of the arrangement of these pipes is shown in Fig. 68, while a detail at one of the main downspouts is shown in Fig. 69.

A special covering was arranged for the drain pipe with its warming pipe; a half section of air-cell covering for 1½ in. pipe was put on the bottom of the 1 in. pipe and wired in place, then an asbestos felted covering for pipe one size smaller than required for the downspout run was wired to the drain; the space between the two was then filled with asbestos cement, and over all a heavy canvas cover saturated in asphaltum was placed. Where pipes were carried between girders, making it impossible to paint and waterproof, a specially prepared asbestos roofing was used in place of the canvas covering and this was cemented by hot pitch at the joints. This system has been in operation during the past winter and successfully met all conditions. Application for patents covering this means of warming pipes of this and similar character is in process.

The heating transmission piping from the power-house to the main building is interesting as regards the adoption of the common 4-elbow and 3-nipple method of caring for expansion. Plate XVIII, already referred to, clearly shows the manner in which expansion is taken care of in the 14 in. main transmission pipes. As no standard brackets were available, special ones were designed for supporting pipes (see Fig. 67), and at the same time an angle-iron frame holding roller bearings to the top of each pipe by means of car springs was worked out. The idea was to hold the pipes down and allow for only a minimum rise or bending upward when steam is first admitted to the pipes. Before these yokes were installed. and at the time steam was first admitted to the pipes, an inspection revealed the fact that the 14 in. mains had bowed up, lifting off the rollers some 4 in. in a distance of 60 ft., thus throwing the weight of this length of pipe on the two brackets at the ends of this 60 ft. length. While this is no more than was expected, it is worthy of mention as indicating the extent to which a pipe will be distorted in a vertical plane, due simply to the effect of the steam first heating the upper part of the pipe. As the pipe became warmed all around, it gradually and easily settled down upon the roller bearings supported by the brackets. Since the

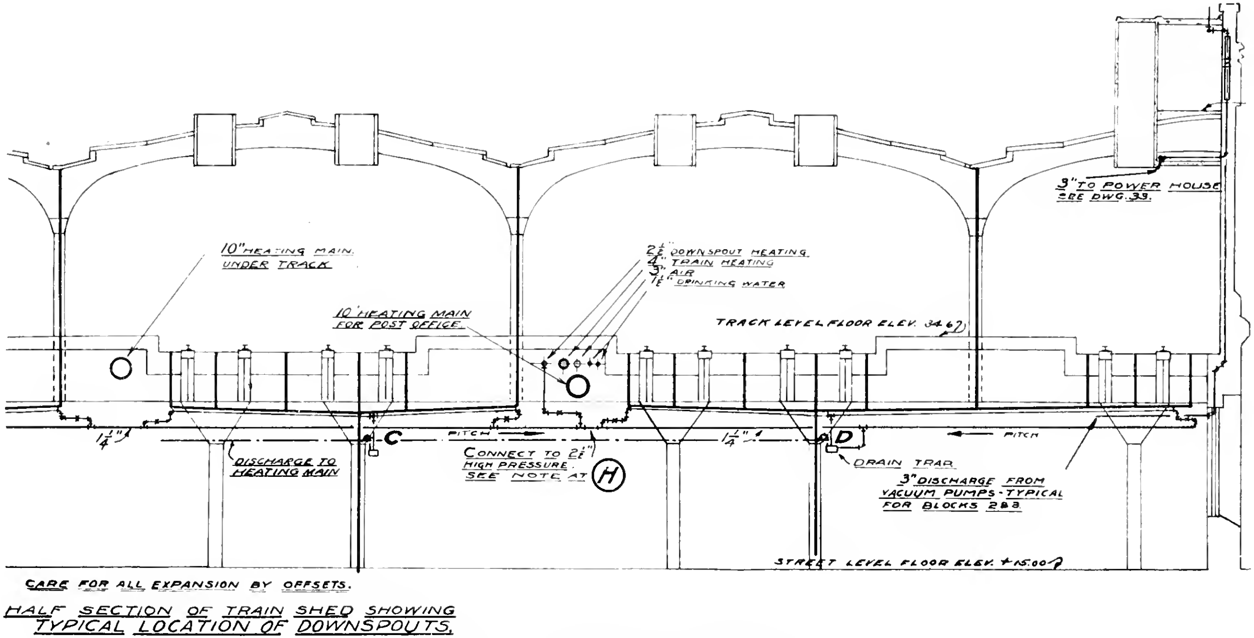
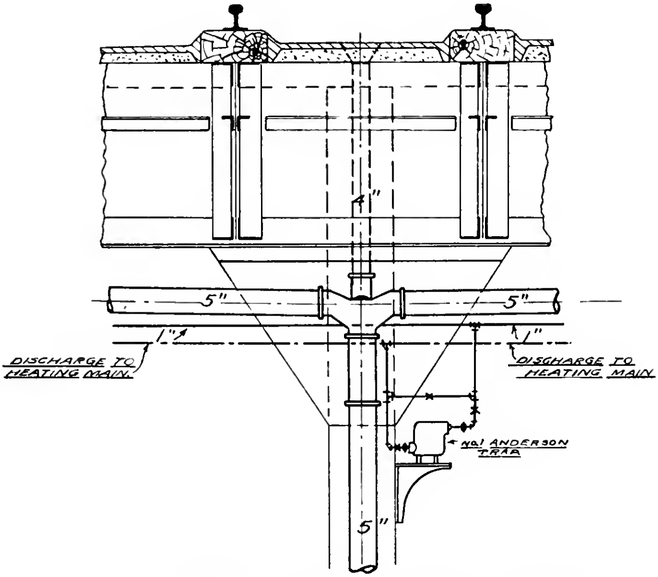

3" TO POWER HOUSE SEE DWG. 33.
10" HEATING MAIN. UNDER TRACK
2½" DOWNSPOUT HEATING
4" TRAIN HEATING
3" AIR
1½" DRINKING WATER
10" HEATING MAIN FOR POST OFFICE
TRACK LEVEL FLOOR ELEV. 34.67
1¼"
C
PITCH
1¼"
D
PITCH
DISCHARGE TO HEATING MAIN
CONNECT TO 2½" HIGH PRESSURE. SEE NOTE AT
H
DRAIN TRAP
3" DISCHARGE FROM VACUUM PUMPS - TYPICAL FOR BLOCKS 2 & 3
STREET LEVEL FLOOR ELEV. +15.00
CARE FOR ALL EXPANSION BY OFFSETS.
HALF SECTION OF TRAIN SHED SHOWING TYPICAL LOCATION OF DOWNSPOUTS.

Fig. 68. Train Shed and Downspouts.

yokes have been installed, the bowing upward is very slight and the longitudinal expansion is apparently completed in a shorter time than before. The pitch given the pipe by this bending upward did not seem to drain the condensation sufficiently to permit the pipe as a whole to become rapidly heated as might be expected. It does not take any longer at the present time to heat the pipe all around with the slight bending than when the 4 in. bending was noted. This, however, is accounted for by the fact of the vacuum system being in operation and rapidly removing the condensation from the pipe, and it is believed that the angle frame or yoke has considerable to do with this, as it does not permit the pipe to rise to such an extent as before.



DETAIL OF DRAIN PIPES AT POINTS A TO D ON "TYPICAL LOCATION OF DOWN-SPOUTS."

Fig. 69. Downspouts, Details.

In making calculations on the expansion of the pipes, the engineers took into consideration the amount vertical pipes would expand upward, due to expansion from heat, and it was found that this was practically equal to the versed sine of the angle through which the vertical pipe was moved by the expansion of the horizontal pipe, and therefore would compensate to an extent which would virtually give a straight line of travel in the horizontal run. However, as steam would ordinarily be fed in at the north end, and the horizontal run at the south end would become heated, and expand somewhat in advance of the vertical pipe at this latter point, the last supporting bracket was set farther back at this end so as to avoid its taking the load of the vertical pipe, with the idea of the main springing or bending in the overhang until relieved by the lengthening of the vertical when heated. This has worked out exactly as anticipated. The expansion connections and details of this transmission piping are clearly shown in Plate XVIII.

The expansion in the long runs below the track structure is cared for by loops conveniently arranged for the high-pressure piping, such as the train-heating main and the main for heating horizontal runs of downspouts. In the 10 in. heating mains, however, no space was available in which to provide loops, and of necessity expansion joints were installed in each pipe. These devices at best are generally very unsatisfactory, especially for high-pressure work, but during the past winter these pipes have been in service and no trouble has been experienced with any of the joints in the heating mains.

The two 14 in. mains are of mild steel, but all other pipe for the heating system is genuine wrought iron. The low-pressure pipe is standard, while the high-pressure pipe, as well as the fittings are extra heavy.

VENTILATION.

The ventilating system throughout the Terminal is one of the most complete of its kind yet installed, the amount of Vento indirect heating-coils for the main building alone being the largest ever placed in a single installation. The measured surface of this is equal to 18,000 sq. ft., which is equivalent to 90,000 sq. ft. of direct radiation. These indirect coils are shown in Fig. 70, before the air washer and casing were built; the tempering coils are on the left, with the re-heating coils shown on the right. Between these two sets of coils, the air washer is placed. Fig. 71 is shown to illustrate the special manner in which the heating coils were installed for the east and west plants of the Madison Street vestibule. The fan is set below the coils and the air is drawn in from the vestibule over tempering coils, is washed, then passes through the fan, and is blown vertically upward through the coils.

One of the complete fan units, as installed in the machinery room, undertrack portion, is shown in plan, Fig. 72. The fan-plants in the main building are similar to this, with the exception that the motor is placed at one end, with the two fans on the opposite end of the shaft; arrangements are made so that air is admitted to both sides of each of the fans. A typical elevation of the main fan-plants in the station building is shown in Fig. 73.

The ventilating plants for the main building are divided into three units,—east, central, and west. Each unit is made up of two fans driven by a single motor. The main entrance vestibule from

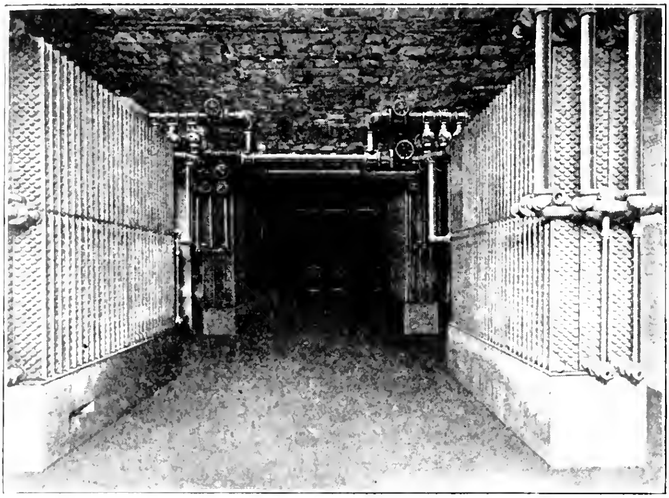


Fig. 70. Indirect Radiation.

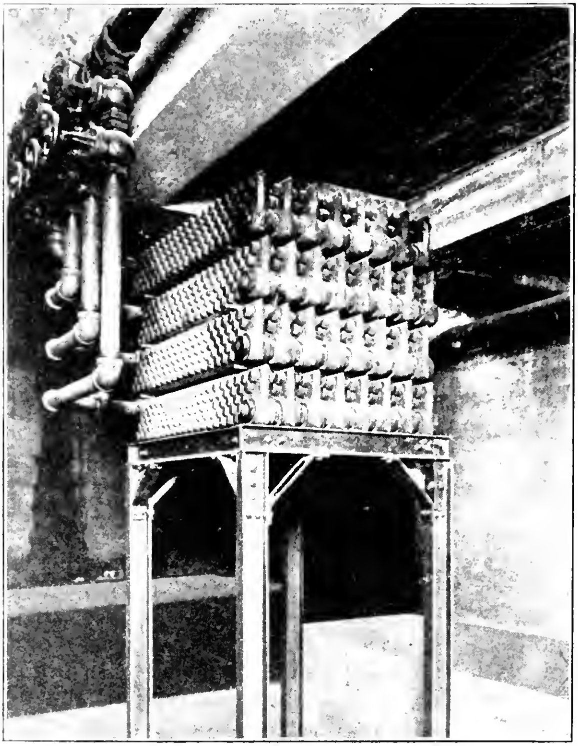


Fig. 71. Special Installation of Heating Coils.

Madison Street has two separate fan-systems, cold air being drawn through grilles placed in the east and west stair-risers, and after passing through washers and reheating coils is delivered again into the vestibules. The Canal Street vestibule-entrance to public space on the first floor is treated in a similar manner with but one fan-unit. The central fan-plant delivers air to the basement baggage storage room, to the baggage room and public space on the first floor, and to the main waiting room on track level floor. This unit has its separate pair of exhaust fans set in the fourth story; likewise the east and west supply-fans have their own separate exhaust-sets. It might be well to mention here the object of taking the air out of the vestibules and blowing it in again. This is done on account of the fact that the natural tendency is for cold air to rush into the vestibules as the outside doors are opened. The intake of the fans catch this before it can reach the doors leading into the main public space and delivers it again as washed air back to the vestibule. The incoming air is fresh, although it may be dirty, but as the washers care for this, the vestibules are sure of a fresh, clean supply of air continuously. The effect has been, during the past summer, that the air in these vestibules was always kept cool and refreshing. In the winter the effect will be to enter a warm atmosphere immediately upon passing through the outer doors.

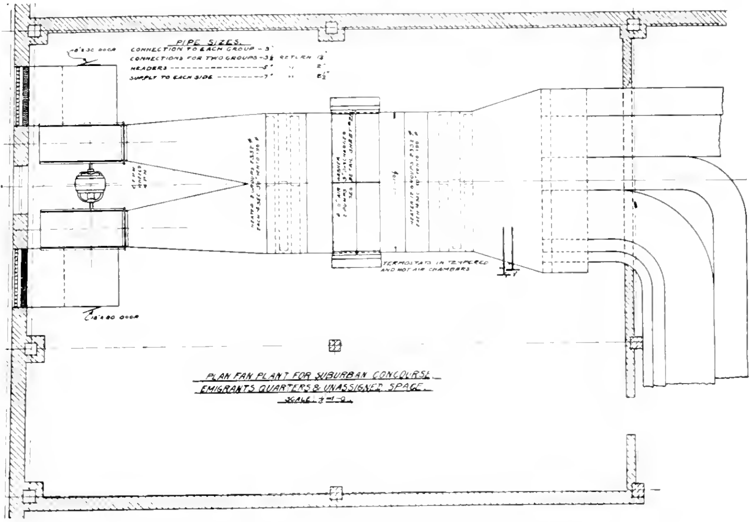

PIPE SIZES.
CONNECTION TO EACH GROUP – 3"
CONNECTIONS FOR TWO GROUPS – 3½ RETURN 1½
HEADERS – 5" " 2"
SUPPLY TO EACH SIDE – 7" " 2½"
TERMOSTATS IN TEMPERED AND HOT AIR CHAMBERS
PLAN FAN PLANT FOR SUBURBAN CONCOURSE
EMIGRANTS QUARTERS & UNASSIGNED SPACE.
SCALE ¼"=1'-0"

Fig. 72. Fan Plant—Forced Ventilation.

Ventilation has been provided in the Dining Room and Women's Room as well as other rooms of a similar nature, but the main heating is done by direct radiation. In the public space on the first floor and the main waiting room on the track level floor, practically the entire heating and ventilation is accomplished by the fan-system, although there are a number of radiators placed on the ledges of the Main Waiting Room immediately underneath the large windows, with the idea of preventing downward currents of cold air.

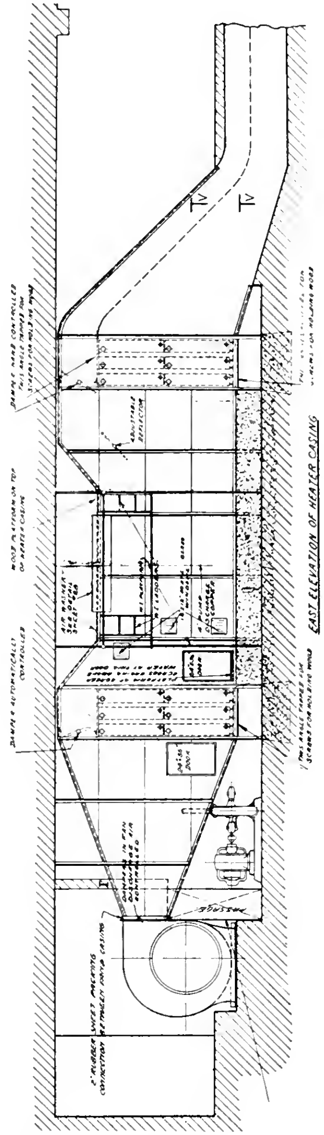


Fig. 73. Fan Plant for Ventilation.

For the main building fan-plants, fresh air is brought into a large chamber running entirely across the building beneath the main vestibule, the air entering through two vertical shafts extending to the top of the building with intakes at the back or north side of the clock towers.

Each of the main ventilating fan-plants delivers into ducts below the basement floor lever, these being connected to plenum chambers, from which smaller ducts are led to the various rooms to be ventilated. The underground ducts have a horizontal partition dividing the heated air from the tempered air, and these are brought into the plenum chambers in the usual manner. The temperature of the air as delivered into the ducts leading to the rooms is controlled by the mixing-dampers operated by air-motor valves controlled from thermostats placed in the various portions of the building. These in most cases are connected to multiple-point accumulators in such a manner that should one portion of the room become heated before the other, the dampers will not operate until the second or even the third thermostat acts.

The success of the ventilating plant as such, particularly in the main building, has been well tested out during the very warm period of weather the past summer, and it has been found that the temperature of the Main Waiting Room and the track-level floor spaces has been from 10 to 12 deg. F. cooler than the air outside of the building, and practically no difference in the humidity has been noted. The air has that perculiar odor of freshness experienced after a thunder-shower, although there is, of course, no ozone present.

Each of the fan-plants is equipped with a hygrodeik for the purpose of determining the relative humidity of the air as it leaves each individual fan-plant, and is also fitted with thermometers.

The air-washers are specially designed and use the water over and over again, there being only a sufficient amount of overflow to carry away the oil and lighter floating particles. The motor-driven centrifugal-pump takes the water out of one compartment, which is separate from the main washer, excepting by connection below the water level, and delivers it for the washer into a pan above. The bottom of the pan being perforated, the water falls in a continuous rain, the streams being large enough so that the impact of the air does not pick up and carry along the spray; they are also sufficient in number to render it practically impossible for any air to pass through without coming in contact with the rain. Baffles or separators are placed beyond the washer to remove any entrained water. The casings enclosing the heating coils and the washer are made of ½ in. ebonized asbestos board, these sheets being bolted to a substantial frame-work made of tee irons. To insure perfect water and air-tight joints, the tees or angles, as the case might be, were ground to a smooth surface and then coated with a special compound; the boards were placed in position, while the compound was plastic and bolted tightly in place with brass bolts. The heads of these bolts were large, round, and very slightly raised so as to keep the inside of the casings as smooth as possible, so as to offer no obstructions to the free passage of the air.

The Post Office is provided with two sets of supply-fans, each equipped with an air washer and heating coils, arranged with the fans discharging into the tunnel below the Suburban Concourse. This tunnel is in effect a plenum chamber from which ducts are led up with openings into the work-room. The scheme of ventilation is one where the air is introduced entirely on one side of the room and exhausted from the other, entering exhaust ducts which in turn are connected to trunk lines leading to the fans. These fans discharge into the mail driveway. As the air changes are sufficient to maintain thoroughly good ventilation throughout the Post Office, the discharge will not be vitiated to any appreciable extent, and being delivered as it is, two purposes are accomplished. *First*, the tempering of the air in the space where considerable work has to be done out of doors. *Second*, it will to a great extent ventilate the driveway, which is of considerable importance as the stable odor might otherwise become offensive.

North of the Suburban Concourse, in that portion designated as Unassigned Space, is a large ventilating fan-plant. (See Fig. 72.) In this illustration the two intakes from Randolph Street are clearly shown. The air is delivered from the fans and passed over tempering coils, washed, and re-heated, then delivered to the Emigrants' Quarters and to the Suburban Concourse. No exhaust is provided for the concourse, as this will be a busy place and entrance doors are opened often, while in addition there are eight staircases leading to the tracks above, the doors of which will be opened to a considerable extent. The Emigrants' Quarters are provided with exhaust, the fans delivering into the automobile space, thus serving double duty by clearing this space of gasoline odors and keeping it free from stagnant air. In the block north of Randolph Street, two fan-plants are installed to ventilate the express rooms and the outgoing-baggage rooms and offices in connection therewith. These two units are the only ones not provided with air washers.

In the main building the air is exhausted from all ventilated portions by fans located in the fourth story, there being three installations provided similar to the delivery-fans in the basement. All of these fans are motor-driven, the motors being operated by remote control from the panel boards at each of the individual delivery fan installations in the basement. On these panels is placed a small Weston ammeter connected with the corresponding exhaust-fan motor in the attic. After the remote control switch is operated, the ammeter will indicate providing the fan is operating, and serves as an indication to the attendant that the exhaust-fan is in service. Separate exhaust-fans are provided for the toilets.

These are run at high speed, creating a very strong suction pressure, which prevents any unbalancing of the ventilating system in these rooms, and under the most adverse atmospheric conditions no odors can escape from the toilets. The public toilets are ventilated by introducing fresh air into the room as in other places, but the exhausts are taken out from each individual closet through a small register located a short distance above the floor.

The kitchen in the basement of the station building is ventilated principally through the hood over the range, which is connected to a large vertical duct made of steel plate, this duct communicating directly with the atmosphere. Where this flue passes through the fourth story, connection is made to a fan, a damper being provided which cuts off that portion of the flue leading to the outside. The damper is held in position by a fuse-link so that in case the flue should catch fire, the link will be fused and the damper will automatically close off the connection to the fan and at the same time open up the clear flue to the atmosphere and protect the fan from being burned out.

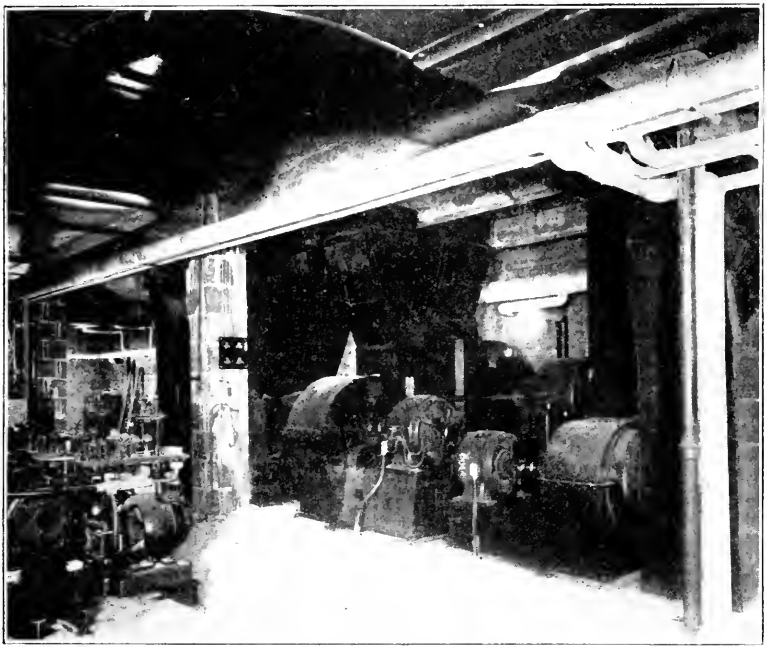


Fig. 74. Fans and Motors.

This installation is shown in the center of Fig. 74. The fan to the right is one of the toilet vent units, while to the left is seen the motors, winding drums, and automatic electric devices for the dumb waiters.

The control for both supply and exhaust fans throughout the plant is designed to permit of wide variation in speed, the motors being of the interpole variable-speed type. During the winter months the motors will be operated at normal speed and when, as in summer time, an increased volume of air is desired to be delivered to the various rooms, the motors will be run at high speed, this being accomplished by field weakening. The same method of control is applied to the centrifugal pumps circulating the water for the washers.

Summing up: There is a total of 15 fans with a combined delivery of 254,750 cu. ft. of air per minute to the main building and undertrack rooms, 28,000 cu. ft. of which is delivered to the Main Waiting Room alone; 20,000 cu. ft. to the Post Office quarters; 10,000 cu. ft. to the pneumatic-tube room in the basement of the Post Office; 48,000 cu. ft. to the other undertrack portions, such as the Suburban Concourse, Emigrants' Quarters, outgoing-baggage and express and mail rooms, etc.

Attention should be called to the fact that all of the register faces in the public spaces are of solid bronze; those faces placed in front of the radiators in the Dining Room and in the Annex to the Main Waiting Room being of very heavy construction and designed to open and afford access to the radiator for adjustment of valves, etc.

TEMPERATURE REGULATION.

The entire heating and ventilating system is designed to maintain a maximum temperature of 72 deg. F. in all of the rooms either heated or ventilated, with an outside temperature of 10 deg. F below zero. A system for the control and regulation of the temperature has been installed.

The medium of operation is air pressure, the system being connected so as to operate not only the radiator and the fan blast coil diaphragm-valves, but the mixing dampers of the ventilating system, and in addition to this to maintain a constant temperature of the heated water used throughout the premises and for kitchen purposes. Thermostats are located at convenient points throughout the heated spaces, various ones operating the radiators and others operating the mixing-dampers in the plenum chambers in the basement so as to provide for the air to be delivered into such portions of the building as they control at a temperature somewhat exceeding that for which the radiator thermostats are set. The purpose of this is to heat and ventilate the building with the indirect radiation as far as possible, and this system to be supplemented by the direct radiation as the temperature of the room tends to fall, there being a maximum predetermined temperature at which the air will be delivered through the registers.

Connections are made by pipe or pipes running from the basement to diaphragm-motors which are connected to dampers in the discharge of each of the attic fans. These dampers, while normally being held closed, can be opened from each supply fan-plant by a simple lever valve mounted on a marble control board. This same arrangement is also installed in each of the attic fan-plants so that the dampers may be operated directly from these points.

There are two plants installed: One is in the basement of the main building, to care for the Terminal as far north as Washington Street. The other plant is installed in one of the fan rooms north of Randolph Street and controls all the apparatus between Washington and Lake Streets. Steam-actuated air-compressors are installed in duplicate for each of these plants.

MISCELLANEOUS APPARATUS.

Pneumatic Tube: The station being divided by the east and west streets, all incoming baggage is delivered on the ground floor level in the baggage room below the Main Concourse, while the outbound baggage is delivered to the baggage room in the undertrack portion between Randolph and Lake streets. Due to this arrangement, it was necessary that some quick means of communication be established between the two baggage rooms, and this was accomplished by installing a pneumatic-tube system with one terminal in the baggage check-room in the main station building, and the other terminal at the outbound baggage room. As it was necessary to have large carriers, the tubes were made elliptical in cross-section 3 in. by 6 in., of seamless drawn brass. The carriers are 9 in. along inside dimensions. The system is of sufficient capacity to care for a total of 15 carriers per minute. The blowers are installed in duplicate, each being driven by its own 7½ h. p. Sprague motor. This plant is located in the basement of the Terminal station building. Tubing, where exposed to cold weather such as in the baggage rooms and where crossing streets and driveways, was thoroughly covered with 1½ in. Johns-Manville asbestos sponge felted covering, made up with 60 laminations per inch of thickness. This protection is necessary, as otherwise there would be more or less condensation in the tubes which would freeze and put the system out of commission.

Refrigerating Plant: An exhaust steam refrigerating plant, of the absorption type, has been installed in the sub-basement of the Terminal station building. This plant was furnished by the Carbondale Machine Company and is of 50 tons refrigerating capacity. It was designed to cool some 6,000 cu. ft. of space, maintaining an average temperature of 38 deg. F. and to cool 400 gallons of drinking-water per hour from 75 deg. to 38 deg. F. The apparatus requires 1,750 lbs. of steam per hour, including that required to operate brine and ice water pumps, steam at not exceeding 10 lbs. gauge pressure. The brine-storage tank is of 3,000 gallons capacity while the water-cooling tank is of about 2,000 gallons capacity. The drinking-water is thoroughly filtered through special No. 77 Loomis-Manning porcelain-lined water-filters, these being provided with coagulating devices. The city water is used for drinking purposes, but it is thoroughly filtered, every precaution being taken to give pure filtered water to the public. A view of the apparatus is shown in Fig. 75.

For the cooling of drinking-water two separate systems have been provided, one to care for the main building and the other for the undertrack portion, including the power-house. The drinking-water fountains in the building open to the public are equipped with double faucets, one of the plain type and the other of the sanitary bubbling type. The latter is used exclusively throughout that part of the undertrack portion occupied by the Post Office, as well as in the Emigrants' Quarters and in the power-house, other than in the engineers' private office.

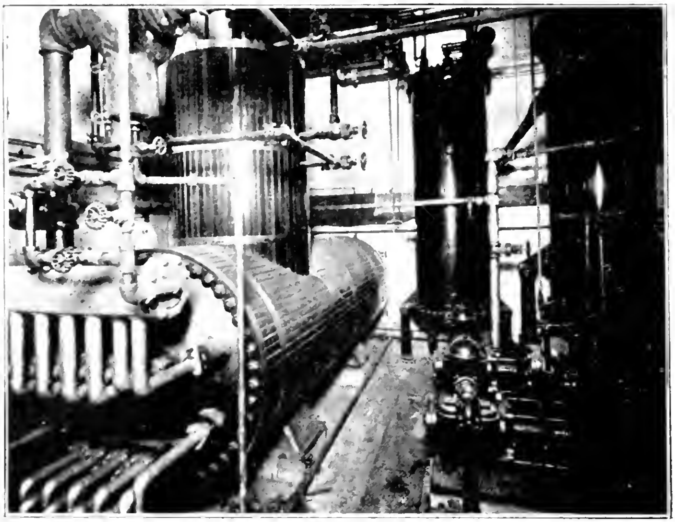


Fig. 75. Water Filtering Apparatus.

One circulating pump takes care of the building, while another takes care of the undertrack portion. The system also cares for all of the cooling rooms and refrigerator boxes used in the kitchen of the restaurant and those installed in the serving rooms, and in addition a large box in the drug store.

As the refrigerating system uses ammonia, the room in which the apparatus is installed was designed with the idea of being able to close it off from other spaces. A separate ventilating-plant has been installed which will entirely clear the room every ten minutes.

Doors have been arranged at opposite corners of the room so as to afford ready egress to anyone working in the plant, should a breakdown occur. All precautionary measures have been taken for the protection of the men operating the system, although no accidents to a system of this kind have ever occurred to the knowledge of the consulting engineers.

A scheme originating with the engineers and adopted by them in several of their installations has been used in the Terminal for the cooling of milk in the serving rooms and lunch counters, refrigerated water being circulated between the outer and inner shell of the milk coolers. This keeps the milk at the same temperature as the drinking-water and renders the use of ice unnecessary. This is vastly more convenient and sanitary than to keep the milk in the refrigerator boxes.

Vacuum Cleaning System: Two complete installations for vacuum cleaning have been made, each of eight sweeper capacity under continuous service. One system is installed in the machinery room in the Terminal station basement to care for the main building, while the other system is installed in the machinery room., undertrack portion, just south of Randolph Street. This cares for all of the undertrack space between Randolph and Washington streets with separate connection leading to the United States Post Office Station U. There is a total of 70 outlets for the two plants. Each plant has a displacement of 480 cu. ft. per minute, the machine in each case being driven by a Sprague variable-speed motor provided with an automatic controlling device so as to automatically bring the sweeper into operation as soon as any outlet in the piping system is opened. The vacuum maintained varies from 10 in. to 12 in., depending upon the number of sweepers installed.

Laundry Dryer: For the convenience of the emigrants, a steam laundry dryer was installed for the drying of their washed clothes, facilities having been provided by the architects in the way of porcelain-lined wash-tubs and other equipment. The dryer consists of three panels carried on anti-friction rollers, all enclosed in an asbestos-lined, galvanized-iron room.

Garbage Destructor: In the under sidewalk space off the boiler room, in the sub-basement of the main building, is installed a garbage destructor for burning the garbage accumulating from the restaurant. The noxious and disagreeable odors caused by the combustion of the refuse are conducted to the chimney through a rectangular sheet-steel flue lined with fire tile. The destructor is 14 ft. long, 6 ft. wide, and 6 ft. high, and has a capacity of destroying 4 tons of miscellaneous garbage and refuse in 24 hours.

Telephones: An intercommunicating or auto-phone system has been provided for—connecting all of the operating departments throughout, from the Terminal station building to the powerhouse and Lake Street tower, including the undertrack portion.

There is a total of 58 telephones with 17 desk extensions. The system operates from a storage battery at 38 volts, is not complicated, and excellent results are being obtained in service.

The automatic telephone switchboard is located in the main switchboard room in the Terminal station basement and can be seen by referring to Fig. 76. The system is that known as the "Couch."

Search Light: A General Electric 24 in. search-light projector is installed in the clock tower room over the east portal to the Washington Street subway. This is arranged to throw the light directly on a mirror, which projects a beam vertically upward through a glass covered opening in the roof. This projector is the regular standard type as used by the United States Navy.

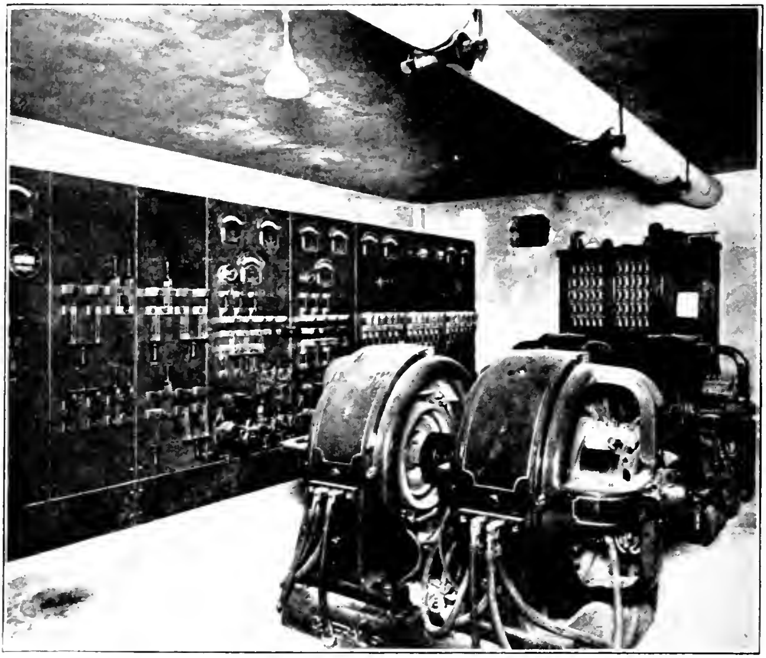


Fig. 76. Switchboard Room and Dynamos.

Fire Alarm: A complete fire-alarm and watchman's-clock system is included in the equipment. Fire-alarm boxes are located at convenient stations throughout between Madison Street and Milwaukee Avenue.

There is a total of 22 stations—13 in the main building, 7 undertrack, and 2 in the power-house. The system is operated on an open circuit but the entire apparatus is always under test. In case of a broken wire or short circuit on any of the lines, the same is indicated at the switchboard by the lighting of two miniature red lamps, also ringing a small test bell. One particularly advantageous feature in connection with this system is that should either one or both of the circuit wires be broken or short-circuited, the system is not put out of commission as the fire alarm will be received, but there will be no test indicated on the system until the break has been repaired. Another feature of note is that should the fire-alarm and watchman's call be turned in at the same time, the fire-alarm call will automatically cut out the watchman, and record the number of the box on the register as well as tapping box number on the electro-magnetic gong.

Two sets of storage batteries are used for operating this system and connections so arranged that the reserve battery may be thrown in before the other is thrown out. It operates on from 20 to 30 volts.

The system is reliable and, it is believed, much less expensive to operate than other systems on the market. The system was furnished and installed by the McFell Electric Company.

A city fire-alarm box has been placed adjacent to the switchboard of the fire-alarm system which permits of an alarm being turned in to the city after it is registered in the switchboard room, thus placing the city headquarters in direct communication with the Terminal station.

Elevator Plant: There are 23 elevators in the Terminal station. Thirteen of them are hydraulically operated, these being in the main building and at the south end of the train sheds. The other ten elevators are electric. The service requirements of these various elevators have already been treated in a paper presented before the Society. The hydraulic elevator system operates under a pressure of 800 lb. The pumping equipment consists of two crank and fly-wheel, three-cylinder, high-duty pumping engines of size 13 in. and 16 in. by 3⅞ in. by 18 in., shown in Fig. 77. In addition there are also two auxiliary, duplex and compounded outside end packed plunger pumps, each of half the capacity of either of the high-duty elevator pumps, and of size 10 in. and 16 in. by 3⅞ in. by 15 in. Pilot valve pumps are 7½ in. by 4½ in. by 10 in. duplex pumps.

Auxiliary Power Plant: In the sub-basement of the main Terminal station building, there have been placed two Babcock & Wilcox vertical header type water-tube boilers set in battery. These are of 150 h. p. each and set with Twin-fire furnaces. In this room is placed the machinery for the vacuum sweeping system, all vacuum and return pumping machinery, and the motor-driven centrifugal pumps for house service. There is also a 1,500 gallon Underwriters' fire-pump, which is connected to the city mains and also takes suction from the Shone ejector pit. This latter connection is to be used for emergency in case of flood.

POWER HOUSE.

The architects—Frost & Granger—are to be complimented for the practical manner in which they worked out the details of the power-house building, in which they happily combined splendid design with utility. It is a power-house in every respect,—dignified, substantial, and of pleasing appearance.

As can be seen by referring to Fig. 65, the main building is located west of the elevated track structure, extending to Clinton Street. The boiler-room floor level is 21 ft. below the sidewalk level with the roof 73 ft. above the floor. The main engine-room floor is slightly over 10 ft. below the sidewalk level with the crane rails 47 ft. 8 in. above the floor, while the total height of the room varies between 60 and 63 ft., due to roof pitch.

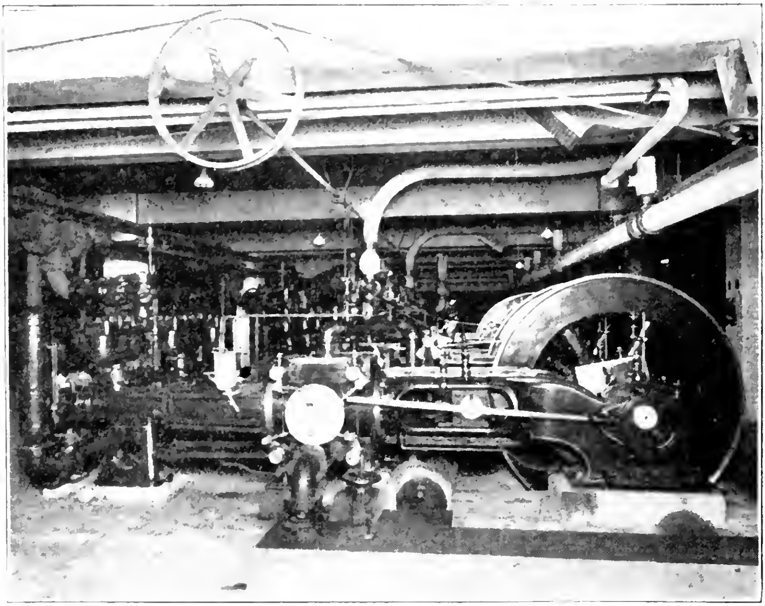


Fig. 77. High Duty Steam Pumps for Elevators.

An unusual arrangement is that the engineer's office is placed between the boiler room and the engine room. Both rooms are in full view from the office. A visitors' gallery extends across the north end and along the west side of the engine room, while the switchboard gallery is at the south end.

Chimney: The chimney is 226 ft. high above the sidewalk level, with the top approximately 245 ft. above the boiler grates. The internal diameter at the base is 11 ft. and at the top 10 ft. 6 in. The base is octagonal to a height of 57 ft. above the street, above which point the shaft is circular, with an external diameter decreasing from 18 ft. at the top of the octagonal base to 13 ft. 6 in. at a point 7 ft. 3 in. below the top, where it widens out and is finished with a heavy cast-iron cap. The octagonal base is of common brick, while the circular section is built of Custodis radial brick. The entire chimney is lined throughout with fire brick 8 in. thick at the bottom and 4 in. at the top.

Lightning Conductor: The chimney is equipped with a lightning conductor furnished and installed by Carl Bajohr; it consists of four lightning-rod points, each having 24 in. tips, 12 in. of which is pure platinum. The points are connected to rods which in turn are fastened to a copper cable surrounding the cast-iron top. Connecting with this cable ring and at the same points where the rods are connected, cables of 256,000 c. m. are carried down diagonally for a vertical distance of 13 ft., where connection is made to conductors, one of which is placed on each side of the chimney. Both of these cables are grounded by suitable plates set a distance of approximately 20 ft. away from the chimney foundation and at a depth which will insure their being continuously in moist earth. In one of these conductors is placed an indicating device equipped with a pointer which will indicate with the passage of current. This also permits of opening up the cable to test the continuity. The conductors are all tinned to prevent possibility of corrosion. The "Y" connection of the cables is novel and is considered of sufficient importance to be reproduced in Fig. 78.

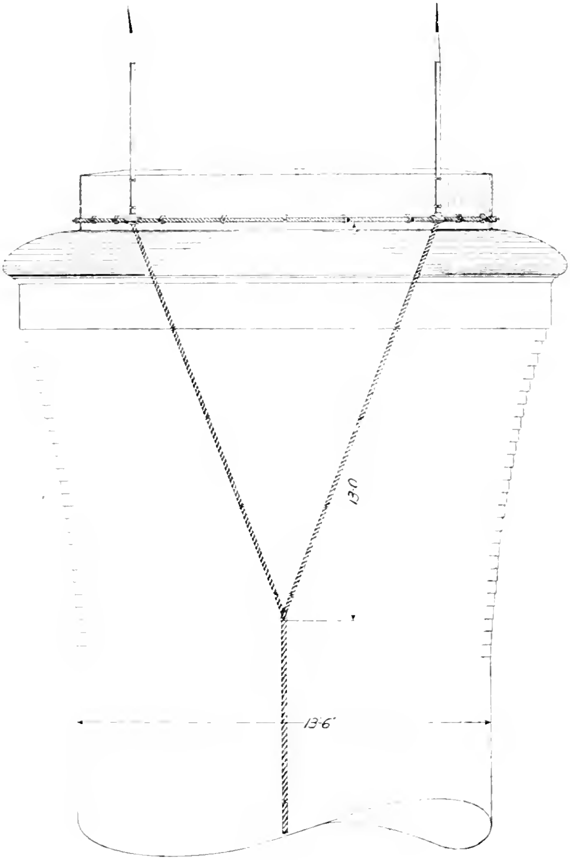
POWER HOUSE EQUIPMENT.

Boilers: The boiler plant consists of six Babcock & Wilcox vertical-header, water-tube boilers, set two in battery. The settings are special in that the boilers are raised some 8 ft. higher than is customary, with the stokers set under the mud-drum end. The design is such as to allow of forcing the boilers to a heavy overload. The setting is such that it provides an extremely large combustion chamber, the gases first passing horizontally below the tubes, there being three gas passes through the tubes. The setting has been unusually successful from the standpoint of eliminating smoke.

The boilers are normally rated at 500 h. p., but with this type of setting 800 h. p. can readily be developed in each boiler with good economy and without excessive forcing.

The side of each boiler battery is fitted with cast-iron plates extending from the front backward as far as the bridge wall and as high as the tile arches above the grates. The object of these is to prevent infiltration of air to the furnace should the brickwork crack on account of the excessive heat. A transverse section of the boiler room looking north is shown in Fig. 79.

The mud-drum on each boiler is provided with three blowoff connections, these being brought off through bent pipe to the side of the stoker as shown in Fig. 80. This drawing also shows how these pipes are connected to the blowoff pipe, which is run above the floor line to the back of the boilers, where it drops into the main blowoff pipe in the trench.



C & N-W. RY. TERMINAL.

Fig. 78. Top of Chimney Stack.

Superheaters: Each boiler is provided with a Foster superheater, guaranteed to raise the temperature of 22,000 lbs. of steam per hour at a pressure of 155 lbs. to 438 deg., or a superheat of 70 deg. F. It is also further guaranteed to superheat 15,300 lbs. 70 deg., and, under extreme conditions, the superheat not to exceed 90 deg. when the boilers are each delivering 27,000 lbs. of steam per hour; the steam pressure in all cases to be 155 lbs.

Stokers: The boiler plant is equipped throughout with Green chain-grate stoker's, the coal being fed to the stoker hoppers through 12-in. well casing, terminating with flared delivery ends.

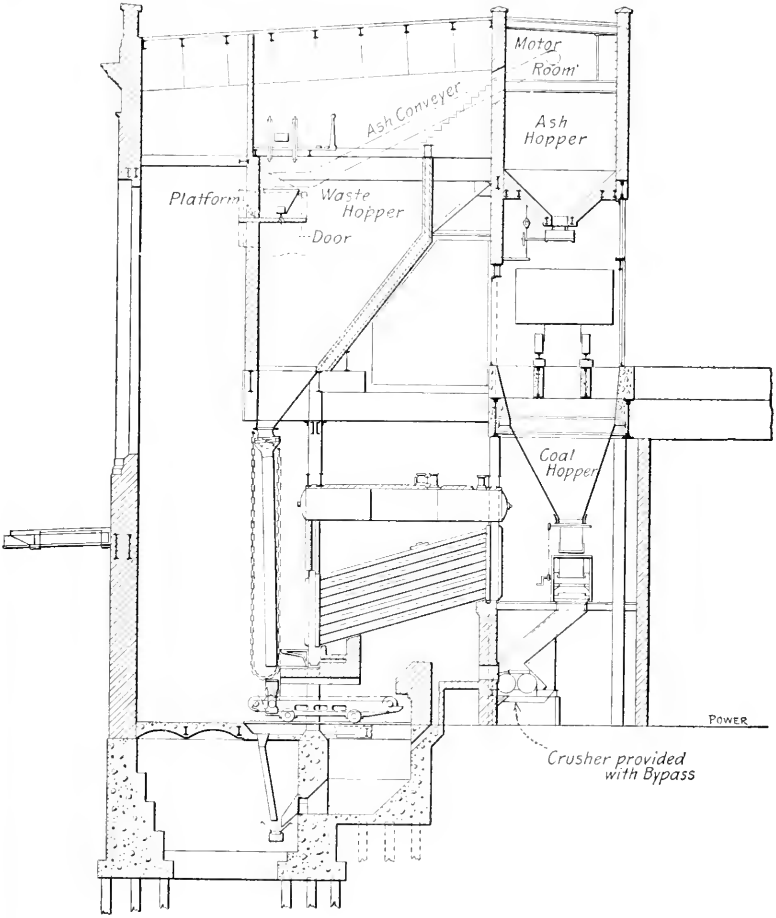


Fig. 79. Boiler Room, Sectional View.

These spread the coal evenly over the entire stoker hopper, and can be clearly seen in Fig. 81. The grates are 8 ft. 6 in. wide by 11 ft. 6 in. long, giving practically 100 sq. ft. of effective grate area. It is calculated that an average of 30 lbs. of coal would be burned per square foot of grate surface per hour, and that 45 lbs.

would be burned when forcing the boilers. The stokers are operated by eccentrics driven by shaft carried below the boiler-room floor.

Soot Blowers: Soot blowers are installed for the purpose of keeping the heating surface clean. These consist simply of an arrangement of piping with nozzles so disposed as to blow the soot from the tubes in all portions of the boilers.

Breeching: The main boiler breeching is all of No. 6 U. S. G. sheet steel, with heavy angle-iron corners, and is further stiffened by 3-in. I-beam frames spaced 3 ft. 6 in. centers along its length, the flange of the beam being riveted to the sheet, it forms a channel guide which is used to hold the insulated covering, the blocks sliding in between the adjacent beams. The main flue is carried in a space to the east of the inclined side of the coal bunkers, and considerably above the top of the boilers, as can be seen in cross-section of the boiler room, Fig. 79. At the north end the steel flue enters, by a telescoping joint, a concrete flue connecting with the chimney

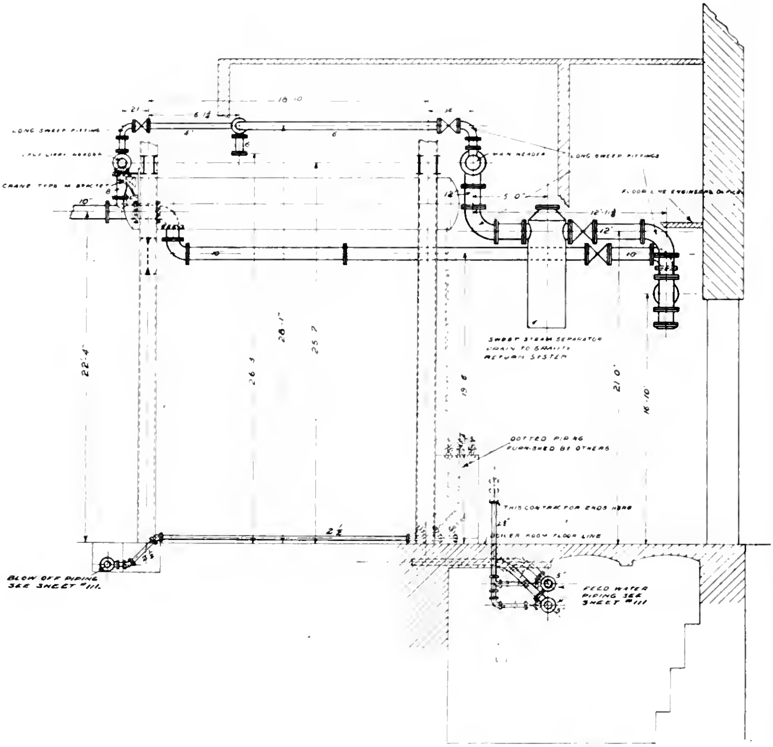


Fig. 80. Boiler Trimmings.

some 40 ft. above the boiler-room floor. At this point the width is 8 ft. and the height 15 ft., an area of 120 sq. ft. This allows 3 sq. ft. of flue area for each 100 boiler horse-power, on the assumption of one boiler always being out of commission and the remaining five developing 800 h. p. each.

One interesting point is the manner in which the breeching supports are arranged to care for expansion. The breeching rests on I-beams running longitudinally, the beams set in cast-iron saddles which rest on car springs held in position by a cast frame which straddles the structural beams. These springs initially, under slight compression, are free to move in any direction and thus take up any movement of the flue due to expansion. The spring supports are shown in the lower left hand corner of Fig. 67.

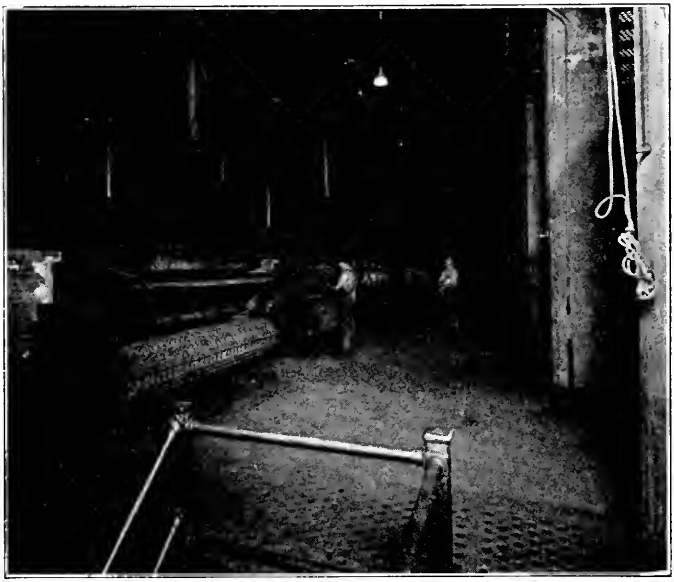


Fig. 81. Chain Grate Stokers.

Coal and Ash Handling Machinery: By reference to Fig. 82, the spur track upon which coal is delivered and ashes removed can be clearly seen. The transverse section through the boiler room, Fig. 79, shows this track together with the coal and ash hoppers, crusher, and conveyors.

The boiler-room floor is about 21 ft. below the sidewalk level, or some 42 ft. below coal car tracks.

The coal and ash handling apparatus has been designed with the idea of handling the coal in carload lots from the track elevation. Unloading-hoppers were provided immediately under the track, these having a capacity of 300 to 400 tons and of a length which will permit of two cars being unloaded at one time. There are three of these coal hoppers, each being provided at the bottom

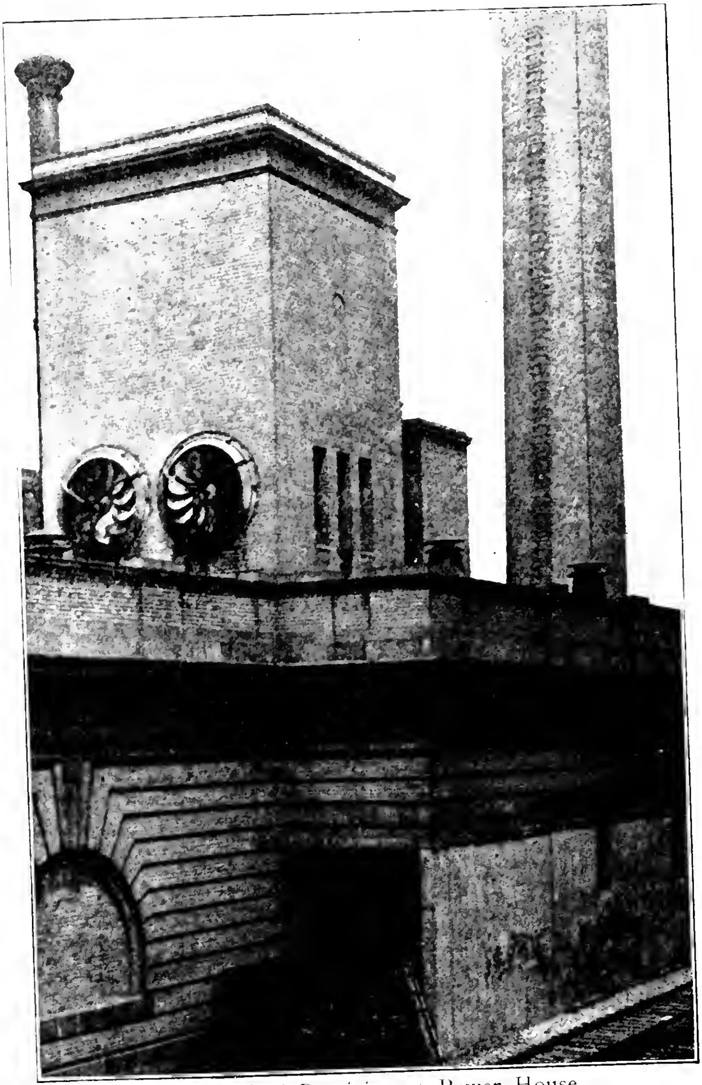


Fig. 82. Coal Receiving at Power House.

with a gate operated by a hand wheel, the coal passing through these gates into a horizontal pan type of conveyor with capacity of delivering 40 tons of coal per hour at a speed of 4½ ft. per minute.

This conveyor passes the coal to a crusher provided with a by-pass onto a small transverse pan-conveyor which travels at 60 ft. per minute and delivers the coal through a chute into a continuous, pivoted, overlapping bucket-conveyor, which travels at a speed of 40 ft. per minute, and elevates the coal to the concrete bunkers over the boilers. These bunkers have a capacity of 750 tons without trimming, or slightly over 1,000 tons when trimmed. Ashes are dumped from the grates into the concrete storage space below the boilers and spouted into the same conveyor which carries the coal. The ashes are raised and dumped onto an inclined pan conveyor which travels at a speed of 60 ft. per minute, delivering ashes at the rate of 40 tons per hour into the concrete ash-hopper located above the coal track. This hopper has a storage capacity of 100 tons of ashes and has two gates for dumping into cars on track.

Engines: Due to the limited space available for the installation of the engines, the vertical cross compound type was selected. There are three engines installed, with 25 in. and 44 in. by 42 in. cylinders, each engine being rated at 1,150 i. h. p. with a steam pressure of 155 lbs. and 60 deg. F. superheat. Space has been left for an additional engine and dynamo unit of the same size. By reference to the plan of the engine room, shown in Fig. 83, it will be seen that the platforms have been designed so that they are all interconnecting, this allowing for maximum convenience of operators passing from one engine to the other. Fig. 84 gives a general view of the main engine units.

Engine guides as well as the main bearings are water cooled.

The manufacturer guarantees the engine performance as follows: At 100 revolutions per minute, with steam at 155 lbs. pressure, and 60 deg. superheat, one-half load, 22.5 lb.; full load, 18.6 lb.; 1,200 i. h. p., 18.6; 1,500 i. h. p., 19.6 lb.

Each engine is equipped with an automatic stop valve, which is operated through a solenoid connected with remote control push-button switches, one set of which is placed at the east end of the bench board. By simply pushing the switch, the solenoid on any particular engine is energized, the core tripping a latch, thus releasing a weight which in falling closes the stop valve and cutting off the steam supply.

Electrical Machinery: To each of the engine shafts is directly connected a 750-kw., 250-volt, continuous-current dynamo. The full-load current of these machines is 3,000 amperes. They will operate normally at 230 volts. The dynamos are what are termed 35 deg. machines, meaning that no part of the machines other than the commutator will attain a temperature of more than 35 deg. C. above the surrounding atmosphere based on atmosphere of 25 deg. C. They are special in the fact that they will carry an overload in current of 25% at 250 volts pressure for a period of six hours, and that they will carry an overload of 100% without flashing or

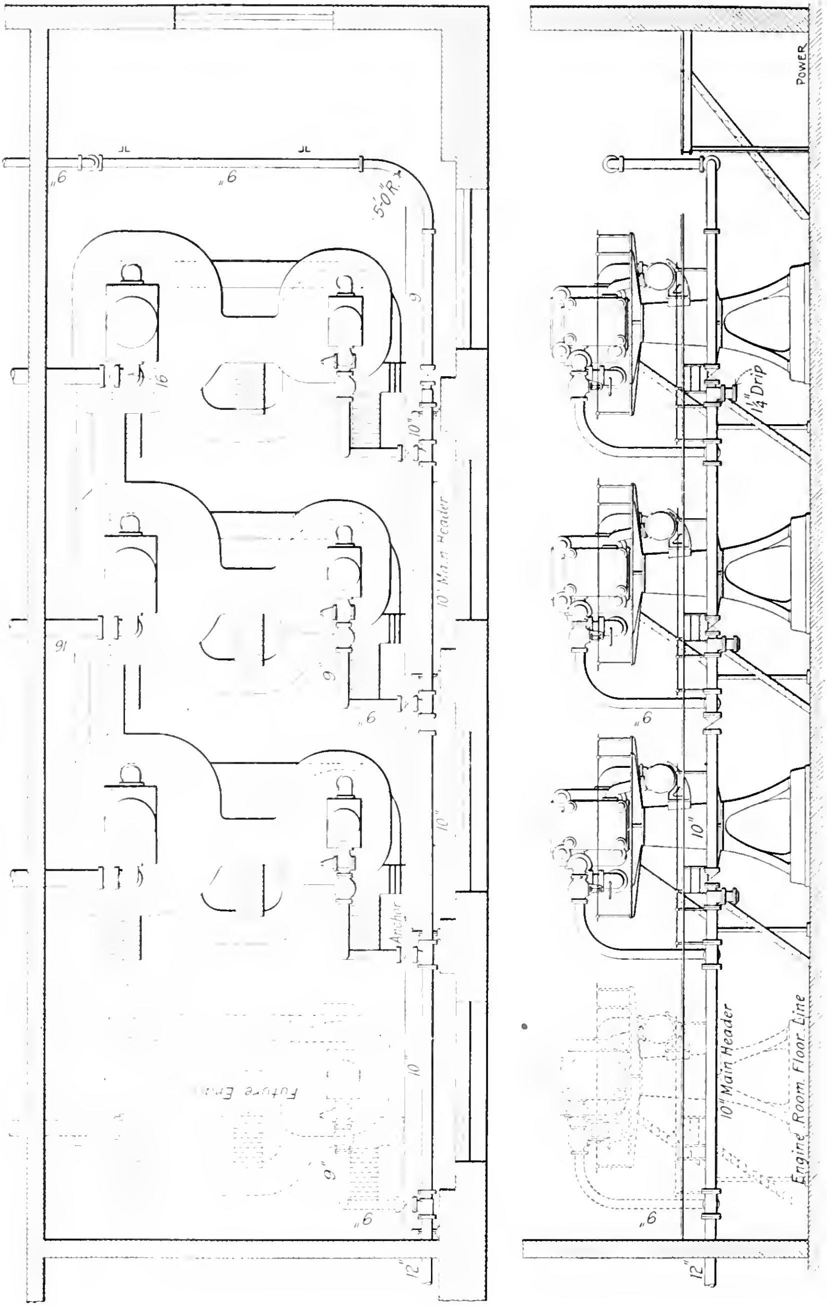


Fig. 83. Plan and Elevation of Engines.

injurious sparking for a period of two minutes. The full-load efficiency of these machines as guaranteed by the manufacturer is 93½%. The dynamos are shown in Fig. 84.

There are two motor-driven, 500-kw., 6,600-volt, three-phase, 60-cycle, alternating-current machines installed for supplying alternating current to the signal towers on the elevated approaches and for the lighting of the subways north of Milwaukee avenue.

The motors are 6-pole, 530-kw. capacity, running at a speed of 720 r. p. m. The commercial efficiency of the combined units at full load is 88%.

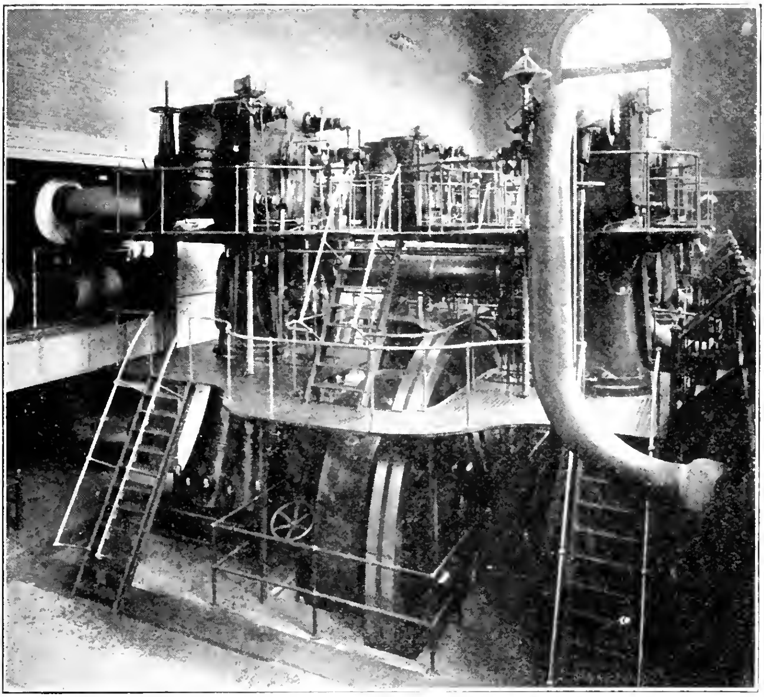


Fig. 84. Engine Room in Power House.

These motor-generator sets are now operated from the D. C. end, but arrangements have been provided so that if it is ever desired in the future to operate them from the A. C. end, it can be readily accomplished with a minimum amount of connections. This was done with the idea that there may at some time in the future be a connecting link between the power station and the railway shops at Fortieth avenue, duplicate units being installed at the shops which would permit of feeding either way. These motor-generator sets can be seen by reference to Fig. 85.

Balancer sets have been provided for three-wire lighting service, two of these being installed in the switchboard room in the sub-basement of the Terminal station building. Each of these has a capacity to care for 600 amperes of unbalanced load, and they not only take care of the unbalancing of the lighting circuits in the station building itself, but feed the three-wire service for the train lighting. One balancer set is installed in the machinery room and the fourth machine in the power-house. These two latter machines each have a capacity to care for a 300-ampere unbalanced load and are connected so that either one may be used in case of a breakdown of the other, these connections being described later.

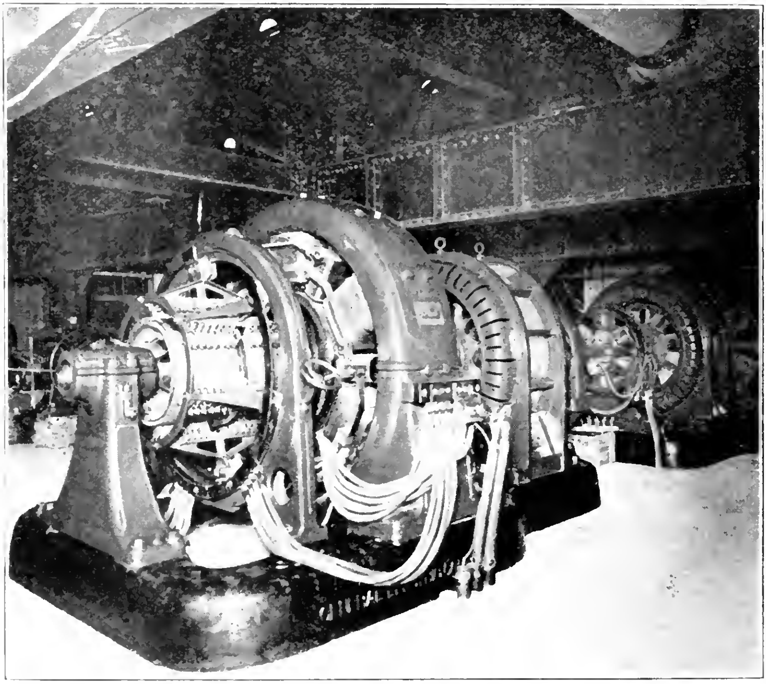


Fig. 85. Motor-Generator Sets.

One Curtis low-pressure steam turbine and generator unit of 500 kw. capacity is installed in the machinery room immediately east of the main engine room, Fig. 86. The exhaust steam for operating this machine is taken directly from the main 30-in. exhaust header. Additional exhaust steam is also furnished from the air compressors, boiler feed, and vacuum pumps. This permits of the utilization of practically all of the exhaust steam from the apparatus in the power-house other than the amount required for the feed water heater.

During practically eight months of the year, this turbine will be in operation, and if plans now in progress are consummated, there will be sufficient exhaust steam for the turbine to be operated during the entire year. At present, however, the exhaust steam from the engines will be utilized during the extremely cold winter months for the heating system.

Air Compressors: Two Ingersoll-Rand air compressors have been installed to furnish compressed air for the charging of air brake reservoirs of trains standing on the tracks in the station, and connection is now being made to the old Wells Street station to supplant the present motor-driven air-compressor units used for operating switches.

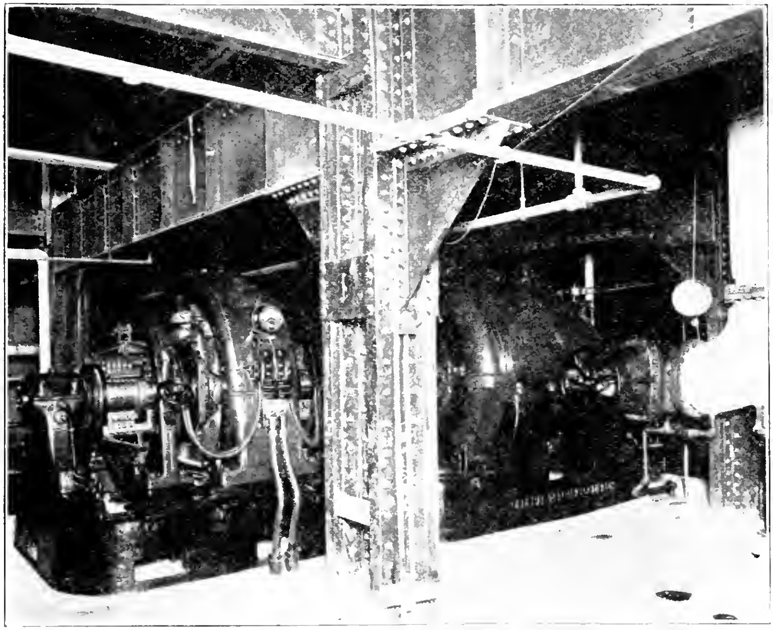


Fig. 86. Turbo-Generator.

Air is also used for operating the Shone ejectors of the sewage system in the power-house and in the terminal station building; also for use in the barber shops. Pipes have been carried throughout the power-house and the terminal station building, with outlets at each generator or motor installation. This air will be used for cleaning the machines.

The compressors are two-stage, steam driven, of the enclosed, self-oiling type, and are equipped with Meyer balanced valves. Each has a capacity of compressing 500 cu. ft. of free air per minute to a pressure of 100 lb. Each has its own inter-cooler as part of the machine, but the system is provided with a large after-cooler, through which all the air passes before being delivered to the distributing mains.

Pumping Machinery: For boiler feed service, two outside, center-packed, Epping-Carpenter boiler feed pumps have been provided. These are duplex and compounded, size 8 in. and 12 in. by 7 in. by 12 in. A space is left for another boiler feed pump of capacity equal to the two present pumps.

A Worthington Underwriters' fire-pump of 1,500 gallons capacity is installed for boiler wash-out purposes, and is connected to a system of piping leading to the coal bunkers to permit of flooding in case of fire from spontaneous combustion.

In the ash pit below the boiler-room floor, an emergency pump has been installed, and is arranged with its suction taken from a sump with the discharge on the sidewalk level outside of the building; it was installed for the purpose of keeping the sub-basement free of water in case of floods from any cause. The valves in the steam and exhaust pipes are placed on the boiler-room floor level so that the pump can be operated without entering the ash tunnel. The pump has a capacity of 450 gallons of water per minute.

The vacuum pumps used in connection with the heating of the power-house and Lake street interlocking tower are installed in duplicate. These are Marsh pumps, 6 in. by 8 in. by 12 in. stroke.

Feed Water Heater: The plant is equipped with one 3,000 h. p. open-type, feed-water heater, set on a platform some 20 ft. up and immediately over the boiler feed pumps. The outline of this, with diagram of piping connections, is shown in Fig. 87.

Power House Drainage: For draining the ash tunnel of such water as finds its way in small amount into the room, a sump has been provided, in which there has been installed a Yoemans automatic electric bilge pump for taking care of the boiler blowoff. In connection with the general plumbing, there has been installed a Shone ejector. The air for the operation of this ejector is provided from the 100-lb. pressure lines, being passed through a pressure-reducing valve which lowers the pressure to that required for the operation of the ejector.

Cooling Tower: The cooling tower is installed on the roof of the power-house. It is 20 ft. square, 35 ft. high, and built of No. 10 gauge steel, with heavier steel used for the cold well below. It is entirely enclosed by brick walls. The tower is of the four-fan type, each fan 108 in. in diameter, with each pair of fans on a single shaft, driven by its own motor, and revolving at a normal speed of 280 r. p. m. The fans are placed 10 ft. apart, center to center. The tower is guaranteed to cool about 3,500 gallons of circulating water per minute from 99 to 84 deg. F., with atmospheric temperature of 75 deg. F. and a relative humidity of 70%, and in connection with the condenser to maintain a condenser pressure of 3 in. absolute when condensing 23,000 lbs. of steam per hour. The filling is made up of 14 layers of interlocking galvanized pipes, 4½ in. diameter by 10 in. high, rolled from plates 14½ in. long by 10 in. wide, of No. 26 gauge. There is a total of 57,400 pipes in the tower, or 4,100 pipes in each course. The arrangement of these interlocking pipes is shown in Fig. 88.

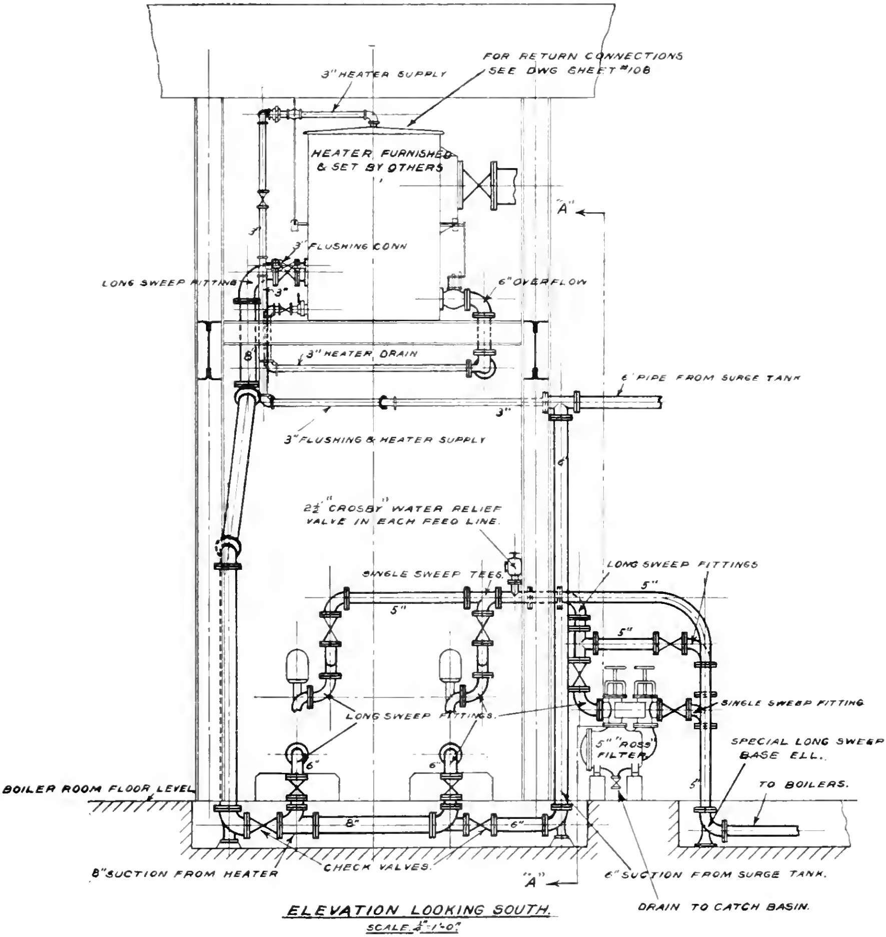
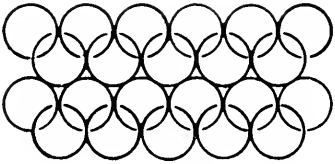


Fig. 87. Steam Boiler Accessories.

During certain portions of the year the fans can be shut down and the tower operated on a natural draft. For this purpose doors have been provided in two sides, as shown in Fig. 89.

The circulating water is delivered to the top of the tower through a 14-in. pipe; from the basin or cold well beneath the tower, water is conveyed by a 14-in. pipe to the motor-driven circulating pump, which forces it through the condenser and back up to the tower. The height of the water in the tower basin is maintained by a float valve operating a switch, which, when the water falls, automatically closes, bringing into operation the motor driving a small centrifugal pump with its discharge connected to the circulating pump suction. The make-up water is all supplied from a tank in which is collected all the jacket water from the air compressors, the turbine bearings, and the guides and main bearings of the vertical engine units. Fig. 82 is a view of the cooling tower from the track elevation. One set of fans is clearly shown. Another view, looking east, is shown in Fig. 89. In this figure the pipe running up close to the tower on the right side is the 30-in. atmospheric relief, while the other pipe is the 14-in. circulating discharge to the tower. To the left of the tower is the motor house containing two 25 h. p. Sprague motors, each of which drives one fan shaft by silent chain.



FILLER FOR COOLING TOWER
AT POWER HOUSE OF
C.&N-W.RY. TERMINAL.

Fig. 88.

Condenser: As part of the condensing outfit in connection with the turbine, there has been installed a Worthington 4,000 sq. ft. surface condenser, containing ¾ in. O. D. No. 18 B. W. G. brass tubes, with tube heads of 1¼-in. Muntz metal, the shell being designed to withstand the static head due to elevation of the cooling tower. A 2-in. two-stage hot well centrifugal pump, with bronze impellers and shaft, delivers the condensate through a Ross filter to the feed water heater at an elevation of approximately 25 ft. above the pump.

The condenser with piping and auxiliaries is shown in Fig. 90.

Oiling System: A gravity oiling system has been installed. All engine oil is delivered to the gravity tank placed at a high point in the power-house with supply pipe leading down to the engine room, where connections are made to all oil cups, the apparatus throughout the plant being equipped with sight feed pressure oil cups. Oil is collected from all of the bearings and carried by pipe back to oil filters, and after passing through the filters the oil is pumped again to the gravity tank. A view of the filters with the pumps is shown in Fig. 90.

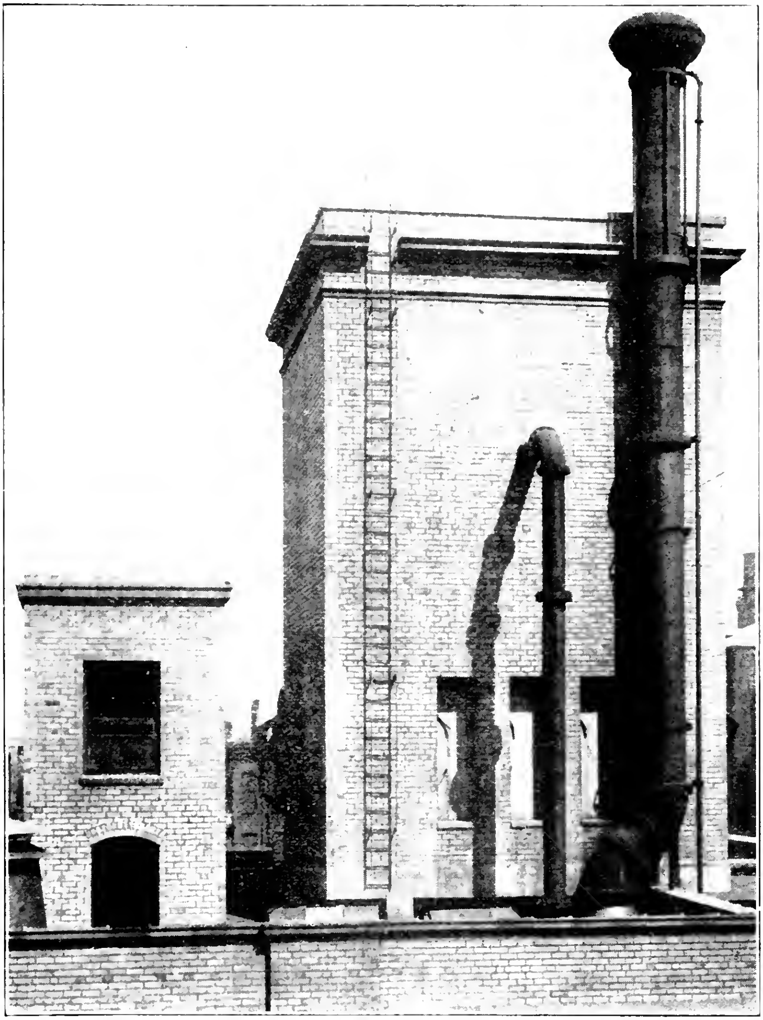


Fig. 89. Cooling Tower.

Crane: The power-house engine room has been equipped with a three-motor, 25-ton Shaw electric traveling crane. The span is slightly over 34 ft. 4 in. With a 25-ton load, the hoisting speed is 10 ft., the trolley travel 100 ft., and the bridge travel 200 ft. per minute. The length of the runway is 107 ft. This crane was used to install the engines and dynamos, and handled without trouble the engine shaft and dynamo armature, weighing altogether 35 tons.

Steam Flow Meter: This is one of the first isolated plants to be equipped with a steam flow meter for measuring the flow of steam in any pipe to which it may be attached. The meter is a curve drawing instrument, giving an accurate record of the rate of flow of steam in pounds per hour. This particular instrument is equipped with an automatic pressure compensating device, and with hand adjustment for temperature variations, the velocity of the steam being measured may remain practically constant, while the pressure and temperature may vary over a considerable range; therefore, to obtain the actual rate of flow in pounds per hour, it is necessary to compensate for pressure and temperature fluctuations. The complete instrument connected to steam pipe is shown in Fig. 91, the details being shown in Fig. 92. Connections for nozzles have been made in various locations throughout the plant wherever it was thought advisable or necessary to take flow readings. At all such points, thermometer wells have been fitted to the pipe so as to determine the temperature of the steam, that the necessary adjustments can be made in the meter to compensate for the varying degrees of superheat.

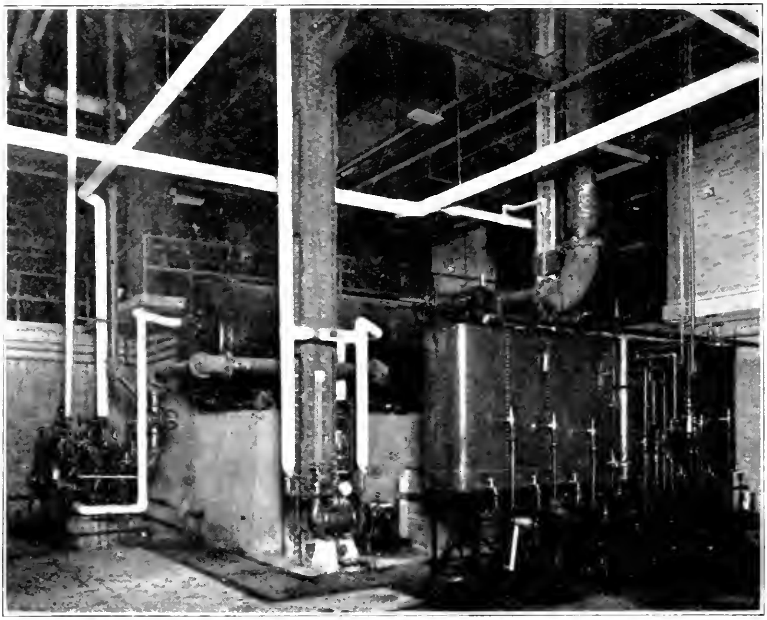


Fig. 90. Condenser and Auxiliaries.

Smoke Recorder: It was the desire of all interested that the plant be operated with as little smoke as possible, and the entire boiler plant was designed with this as one of the governing features.

That an accurate record might be kept of the stack conditions as regards smoke emission, an Eddy smoke recorder was placed in the boiler room, where it is visible to the fireman. The connections made to the chimney are without valves, so that they cannot be tampered with, and the instrument itself is enclosed in a glass case provided with a lock.

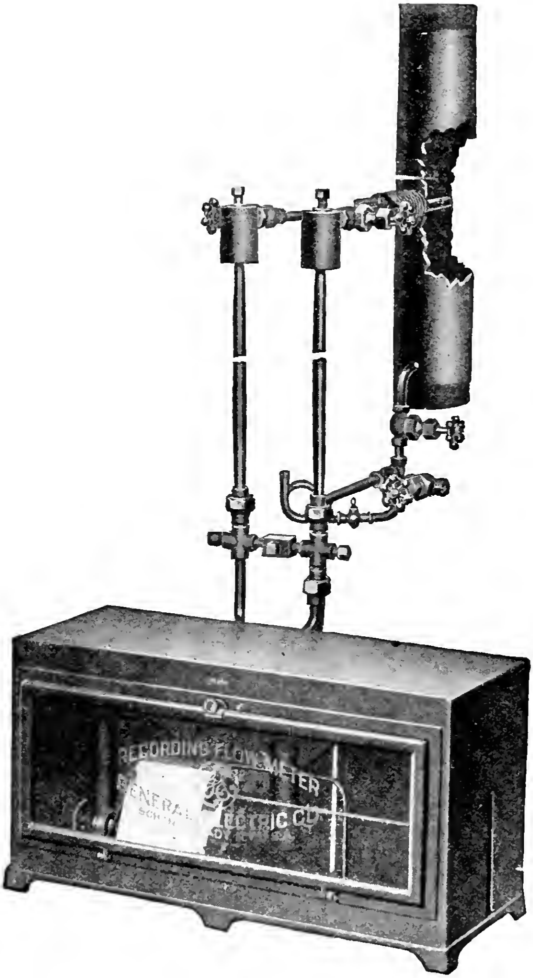


Fig. 91. Steam Flow Meter.

It is a well-known fact that with careful firing the economy of the boiler plant is bettered and at the same time there is a minimum of smoke due to the fact that the furnace combustion is more perfect. As these are co-related, we would naturally look for good furnace conditions if there was an absence of smoke, and if we obtain a smokeless chimney, the other follows.

The principle of the recorder is very simple. Its primary elements are a pump, a tube leading from the pump to the chimney, and another tube having a small discharge orifice and leading from the pump to the neighborhood of a sheet of porous white paper. The pump draws the chimney gases through the first tube and forces them through the second in a fine stream against the paper. The coloring matter in the gases, whatever it may be, is driven into the pores of the paper, and thus the record is made. The gases on their way from the chimney to the pump are first passed through a condenser and then across a surface of sulphuric acid in a closed vessel. This is for the purpose of removing the water vapor carried by the gases.

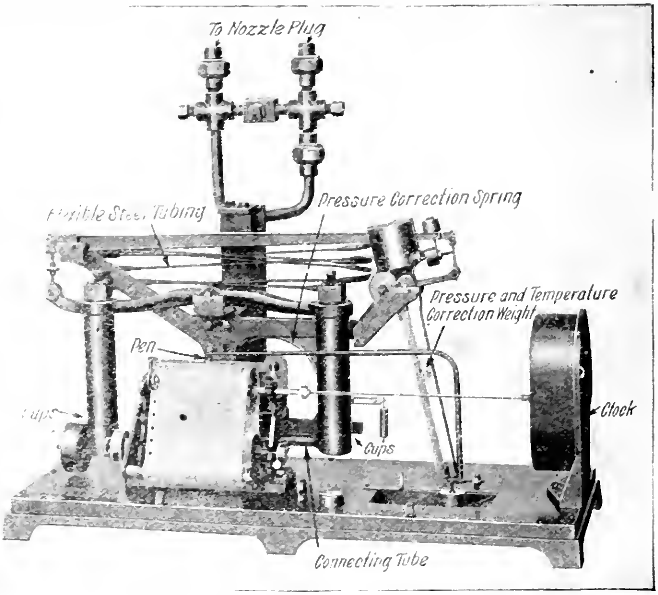

To Nozzle Plug
Flexible Steel Tubing
Pressure Correction Spring
Pressure and Temperature Correction Weight
Pen
Cups
Clock
Cups
Connecting Tube

Fig. 92. Steam Flow Meter—Details.

The instrument, as installed, is shown in Fig. 93. That an idea may be had of the manner in which the varying density of smoke is recorded, a typical chart as made by one of these instruments is produced in Fig. 94. Since the Terminal plant has been in operation the charts show no marking whatever.

Power House Piping: The entire system of piping throughout the power-house has been reduced to a minimum; the piping arrangements are simple and direct.

The piping at the boiler plant is shown in plan and elevation in Plate XIX, and the engine-room piping and connections are shown in plan and elevation, Fig. 66. The relative location of engines, exhaust steam turbine, air compressors, and condensing apparatus, together with all of the piping, are clearly shown.

Wrought-iron pipe is used throughout, with the exception of the pipe bends at the boilers and engines, where mild steel pipe is used with welded flanges. The high pressure fittings and valves are extra heavy Ferrosteel, as manufactured by the Crane Company, and suitable for a working pressure of 250 lbs. The exhaust piping is all standard with the same class of fittings, the valves used in connection with this work being for 125-lb. working pressure. All valves, with but few exceptions, are of the outside screw and yoke, rising stem pattern. The flanges are raised face and given a cold water finish. The gaskets used throughout on the high pressure work are the McKim double-jacket, inside-ring type, while in connection with all of the exhaust piping Tauril packing is used; the gaskets in the condensing system are cut out of 12-oz. canvas. which was thoroughly saturated with red lead and the joint pulled up before this hardened. For draining all of the high-pressure piping, a Holly gravity return system has been provided.

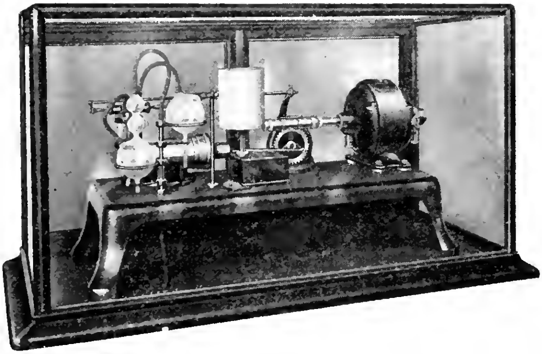


Fig. 93. Smoke Recorder.

All precautions were taken to prevent a shut-down of the machinery due to any ruptures in the piping system. An auxiliary high-pressure boiler header is provided, this being of considerably smaller size than the main header and carried at the rear of the boilers. The pipe is extended, running to the south end of the engine room, where it is connected with the main steam-pipe by which the engines are generally supplied. All of this piping is suitably valved and cross-connected so that either the main boiler header or the auxiliary header can feed either side of the loop.

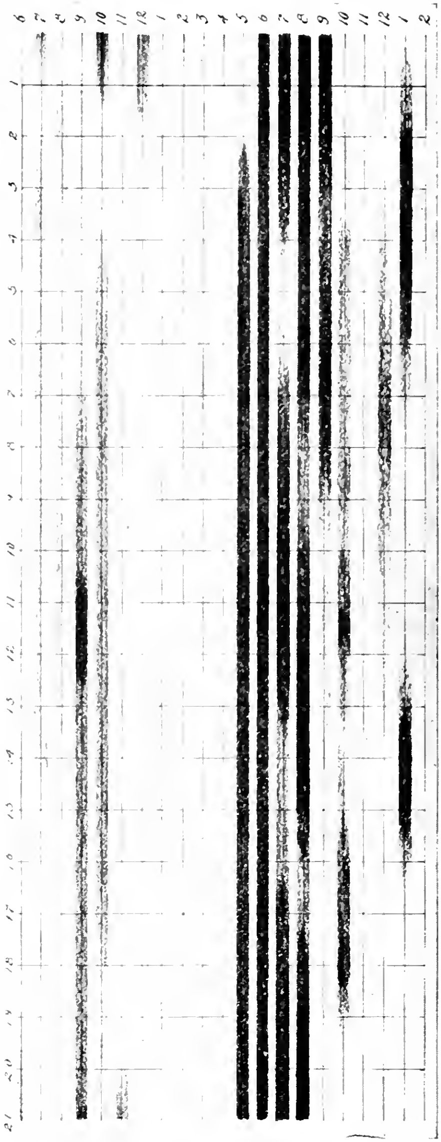


Fig. 94. Chart from Smoke Recorder.

Two separate mains are run for boiler feed service. These are carried below the boiler-room floor and valved below each boiler so that either header or both may be used for any one or all of the boilers, as the case may be. This piping is shown in Fig. 80. In the boiler feed line there is placed a filter for the purpose of catching any oil which may possibly find its way into the feed water heater.

The piping is covered with a very high grade of insulating material, known as asbestos sponge felted covering, 2 in. in thickness; this is applied in two layers, each 1 in. thick, breaking the joints. The boiler feed pump discharge and connections to the boilers, as well as other minor piping throughout the plant, is provided with the same covering, but it is 1½ in. in thickness, applied in one layer. All flanges on the high-pressure piping are protected with the same covering 1 in. in thickness.

This covering is made of many layers of strong felt, composed of best quality asbestos fibre, and fine particles of sponge. Due to the nature of the material, there is an infinite number of small, confined air-spaces which account for its remarkable insulating properties. This covering was selected on account of the fact that its efficiency is maintained indefinitely; it does not deteriorate, and abuse does not injure it.

The boiler breeching is covered with 2-in. vitrified asbestos, air-cell covering. The sheets are held in position by steel channels, angles, or tees, and are thoroughly wired in place; all joints are closed with special cement.

ELECTRICAL FEATURES.

Switching: The switching arrangements for the power-plant are as complete as any ever installed in a plant of this character. The space available for a switchboard was restricted. This, combined with the various classes of service to be furnished, rendered it advisable to follow the practice established for large service companies' plants, but modified to accommodate the space and the service. All the continuous-current machines are coupled to a system of busses through automatic remote-control circuit-breakers; likewise the motors driving the 6,600-volt A. C. machines are started automatically through contactors, while the exciters are connected to other busses and to the fields of the A. C. dynamos; also the A. C. dynamos to the high-tension busses through automatically-operated oil-switches. Each outgoing A. C. line from the power-house is controlled by its own oil-switch, all operated by remote-control switches from a distributing panel. The D. C. feeders are controlled by knife-blade switches in the customary manner. All machines are controlled directly from the bench board and all feeder circuits from the distributing board. Fig. 95 shows the bench board to the left and the feeder board to the right.

Continuous current of 250 volts, 2-wire, is furnished for the

Terminal station building; likewise for the under-track portion, with the addition of a cross-connection between the three-wire balancer set in the power-house, with that in the machinery room, under-track portion. Alternating current, 6,600 volts, 60-cycle, three-phase, is used for transmission north of the power-house for interlocking towers and for subway lighting, while 230-volt A. C. service is delivered to the Lake street interlocking tower, where, by the use of an auto transformer, 230-volt or 115-volt current is available. Direct current service is furnished the Lake street tower for lighting the building and for charging storage batteries for the signaling system. Switching arrangements are made so that either A. C. or D. C. current can be used exclusively in this tower should there be any trouble with either service. This precaution was deemed advisable for this tower, as it is the most important one.

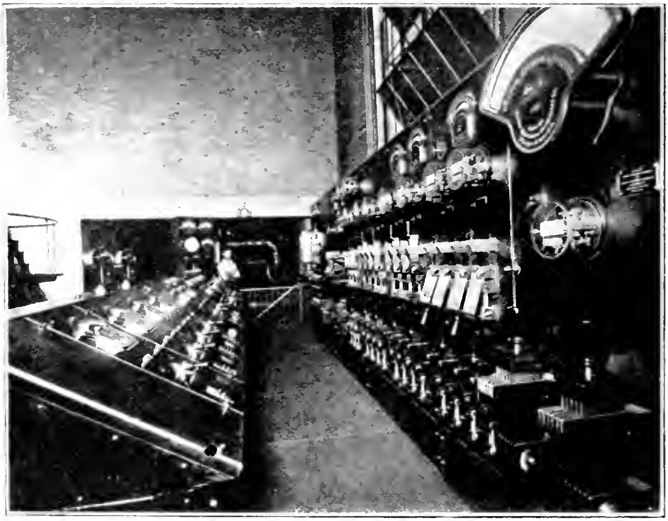


Fig. 95. Bench Board and Feeder Board.

In the power station, the remote-control feature in connection with the A. C. apparatus is substantially that in general use for 6,600-volt work. In connection with the D. C. apparatus, the control has been somewhat elaborated, due to the special conditions existing in the plant, such as the motor-generator sets being operated from the D. C. end and the operation of the circuit breakers, which are used as line switches connecting the D. C. dynamos and the turbo generator with the system of busses.

As already stated, the space in the power-house was limited, and it was such as to practically prohibit the design of a switchboard which would contain the machine switches, circuit breakers, and equalizing busses, without double-decking. This was out of the question; therefore tunnels were provided in which the main system of copper bus-bars were run and each machine connected thereto and to the equalizer. Each bus is made up of four ¼-in. bars, 7½-in. deep, with ¼-in. spacers.

The remote-control circuit-breakers for the 750-kw. D. C. generators have a nominal rating of 4,000 amperes. These are installed in recesses in the engine foundations leading off from the tunnel running north and south along the west side of the power-house below the engine-room floor. By the use of these appliances, placed in this manner, economy of space, not otherwise available, is secured, at the same time simplifying the switchboard and increasing to a marked degree the flexibility of the switching system. Thus the switching apparatus for each individual unit in the power-house is placed in close proximity to its unit. The remote-control switches are placed on the bench board on the platform as described, and all of the various circuit breakers of the D. C. dynamos and those installed in connection with the motors of the motor-generator sets, together with the automatic motor-starters, are controlled from this point. In addition, the oil switches for the 6,600-volt motor-generator sets are operated from the bench board.

The 4,000-ampere circuit-breakers for the three engine-driven units and the 3,000-ampere circuit-breaker on the exhaust turbo generator are three-pole, 250-volt, two-coil overload, reversite, Dalite and Auto-ite motor operated, remote control "I. T. E." breakers. These are electrically and mechanically interlocking. In operation they close without the least shock or jar, as instantly upon the start of the closing movement the control switch is automatically short-circuited by the closing mechanism, and the movement is thus completed without further action on the part of the operator.

The circuit-breakers used in connection with the motors for driving A. C. generators are of the same general type, but are single-pole, two being installed with each motor. By closing the control switch on the bench board, one of these single-pole breakers is closed, thus permitting current to pass through the contactors, closing one after the other, gradually cutting out the external starting resistance, the closing of the last contactors automatically closing the short-circuiting motor-operated switch or circuit-breaker.

The main dynamo circuit-breakers are shown in the view of the tunnel, Fig. 96. This also shows the voltmeter, ammeter, and watt meter as mounted on swinging brackets, each machine being so equipped. Fig. 97 is a view of the pit below the motor-generator sets where the breakers are installed for these machines, and for the turbine generator whose electrically operated field-rheostat can also be seen in the background.

Resistances have been placed in series with the field of each of the motors of these motor-generator sets, so as to permit of syn chronizing, the bench board being equipped with all synchronizing devices.

All of the generators and the fields of the A. C. machines, with the exception of the exciter fields, are equipped with electrically-operated rheostats, each being controlled from its generator panel on the bench board by means of a push-button switch.

The exciters for the A. C. machines are connected directly to the busses without any circuit-breakers or fuses, remote-control switches on the bench board bringing contactors into operation which connect the exciters to the busses. Each exciter is directly connected to the shaft of its motor-generator set. Conditions rendered it necessary to devise some arrangement to prevent a short circuit when throwing the dead exciter on to the busses as a motor, in case of an accidental manipulation of the remote-control switch on one of the dead exciters. This is accomplished by placing in one of the legs of each of the exciters a reverse-current relay, which acts upon the reversal of current and closes the circuit through an auxiliary relay placed on the bench board; this relay opens the circuit through the closing coil of the contactor connecting the exciter

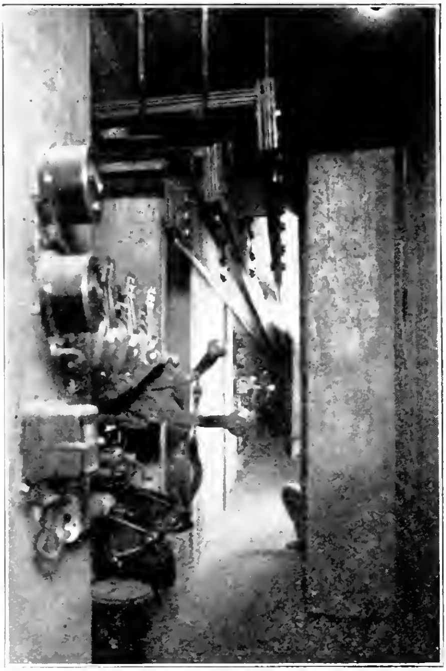


Fig. 96. Circuit Breaker.

busses, and at the same time closes the circuit to a bell, thus indicating to the operator that the dead exciter has been thrown on to the bus-bars.

This installation called for some special arrangement in connection with the opening of the field circuits of the A. C. machines. Inasmuch as everything is under remote control, it was not possible to use the ordinary field switch without unnecessarily complicating the wiring. The arrangement worked out for this consisted of placing a connection on the extended shaft of the exciter-circuit remote-control switch at the bench board, this being in the form of a triangular contact which would enter blades when the switch was opened, these blades closing a circuit through the closing coil of a

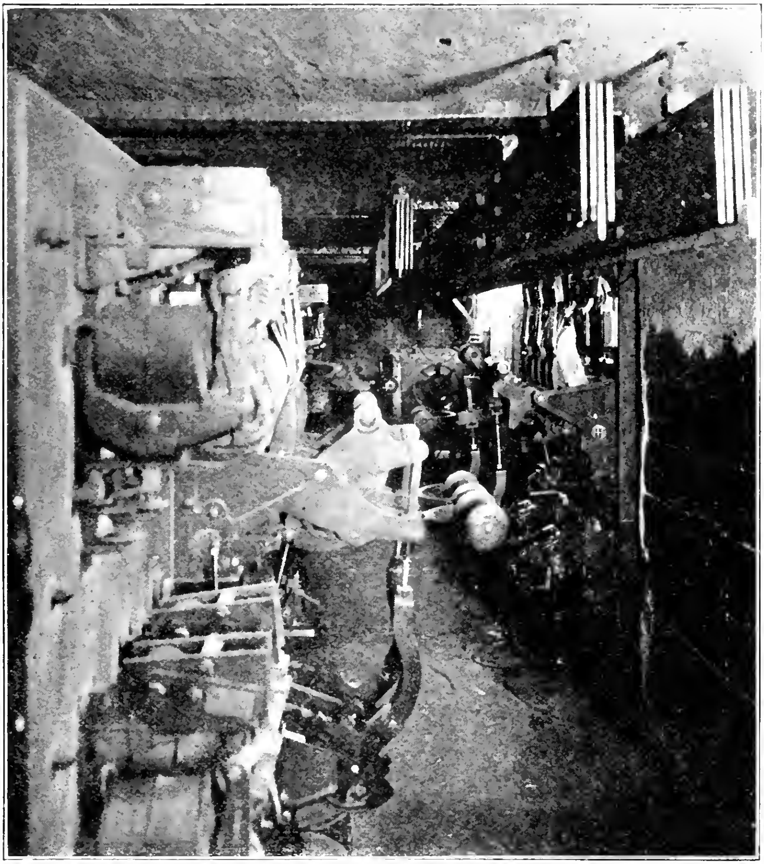


Fig. 97. Electric Machinery Below the Motor-Generator Sets.

small contactor which connects the discharge resistance across the fields.

The machine oil switches are mounted on a platform or mezzanine floor above the motor-generator sets. A diagram of the connections is shown in Plate XX.

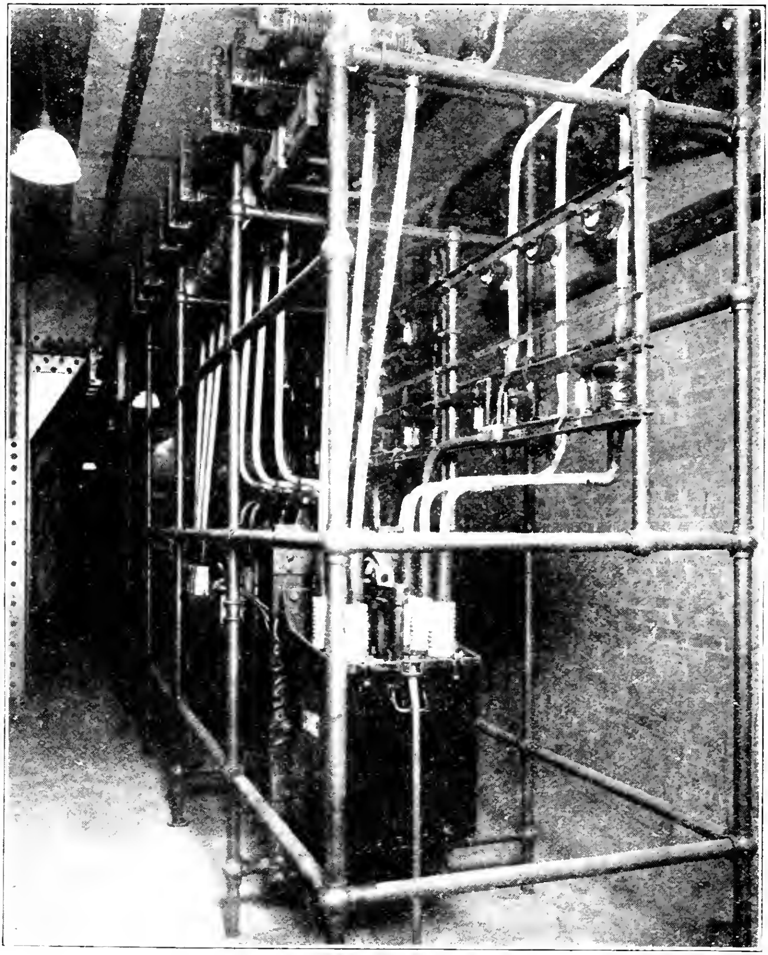


Fig. 98. High Tension Oil Switches.

The high-tension oil switches for the service north of the power-house are placed in a separate room, a view of which is shown in Fig. 98. The wiring diagram for this high-tension room is shown in Plate XXI. The switches are General Electric, three-pole, 300-ampere, 15,000-volt, K-12-type oil switches and are equipped with the regulation closing solenoids. In addition, they are fitted with tripping devices adjusted to automatically open the switch on a predetermined overload or "short" on the outside lines, or from the control switch on the feeder panel of the distributing board when it is desired to open the circuit.

Connections are made from the A. C. machines to the switches, and from the high-tension busses to the service room, by three-conductor lead-encased cable drawn in iron conduit. The insulation is varnished cambric and is for 10,000 volts working pressure. The lead sheath is grounded to the conduit through the pot heads. All high-tension single conductors used throughout are provided with the same insulation, but finished with asbestos flame-proof braiding. Precautions have been taken to prevent static discharges from all conductors.

In the under-track portion there is provided a remote control, 500-ampere, two-pole switch for connecting the feeder lines to the mains in the block between Randolph and Washington streets. This is operated automatically, a knife switch being closed to start the balancer set, which, when up to speed, closes a contactor which connects the neutral of the balancer set to the neutral bus at the switchboard. When this latter contactor closes, connections are made so as to energize the closing coils on the 500-ampere remote-control switch, connecting the two outside legs of the system. It will thus be seen that it is impossible to close the outside legs of the three-wire system until the balancer set is brought up to speed and ready to take its load when the contactor in the neutral main is closed. Auxiliary contacts are provided to close the circuit of the opening coils of the remote-control switch when the second contactor releases.

Each balancer set is connected to the lines by a series of contactors brought automatically into operation by the closing of the knife switch on its switchboard panel.

The complete control and distributing wiring, which permits of all of the switching arrangements as mentioned, are shown in Plates XXII, XXIII and XXIV, these being respectively the wiring diagram of the bench board and the machine it controls; the wiring diagram for feeder board and service room, and wiring diagram for main building and under-track switchboards, with connections between the power-house and these boards.

Switchboards: In the power-house on the gallery at the south end is placed the controlling or bench board, and a main distributing board controlling the supply of current to the main station building and under-track portion. A view of these two boards is shown in Fig. 91.

A distributing switchboard for under-track and train shed service is installed in the machinery room in the unassigned space, south of Randolph street, while the main receiving and distributing board

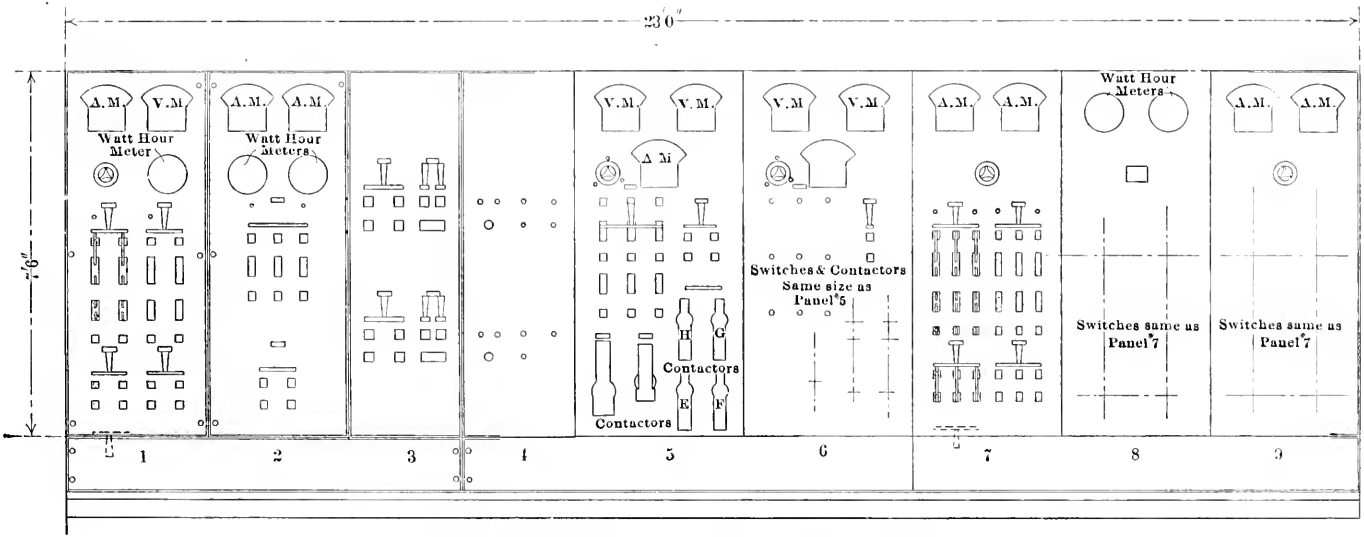


Fig. 99. Switchboard—Terminal Station Building.

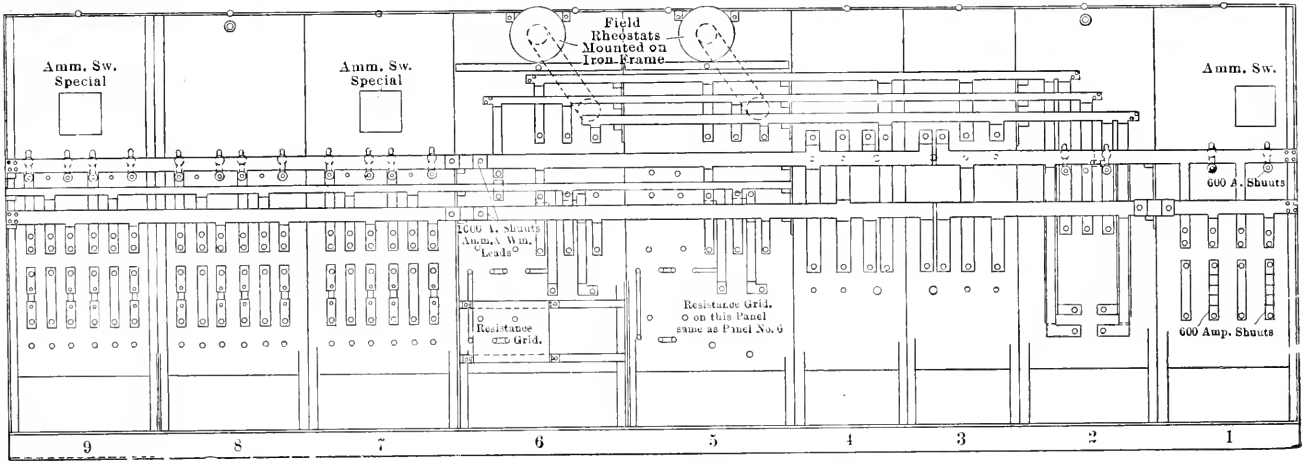

Amm. Sw. Special
Amm. Sw. Special
Field Rheostats Mounted on Iron Frame
Amm. Sw.
600 A. Shunts
1000 A. Shunts Amm. & Wm. Leads
Resistance Grid.
Resistance Grid. on this Panel same as Panel No. 6
600 Amp. Shunts
9
8
7
6
5
4
3
2
1

Fig. 100. Rear View of Same Switchboard.

for the Terminal station building is placed in the basement of the building. This latter board is shown in Fig. 76. A diagram of this distributing board is shown in front view, Fig. 99, and a rear view in Fig. 100.

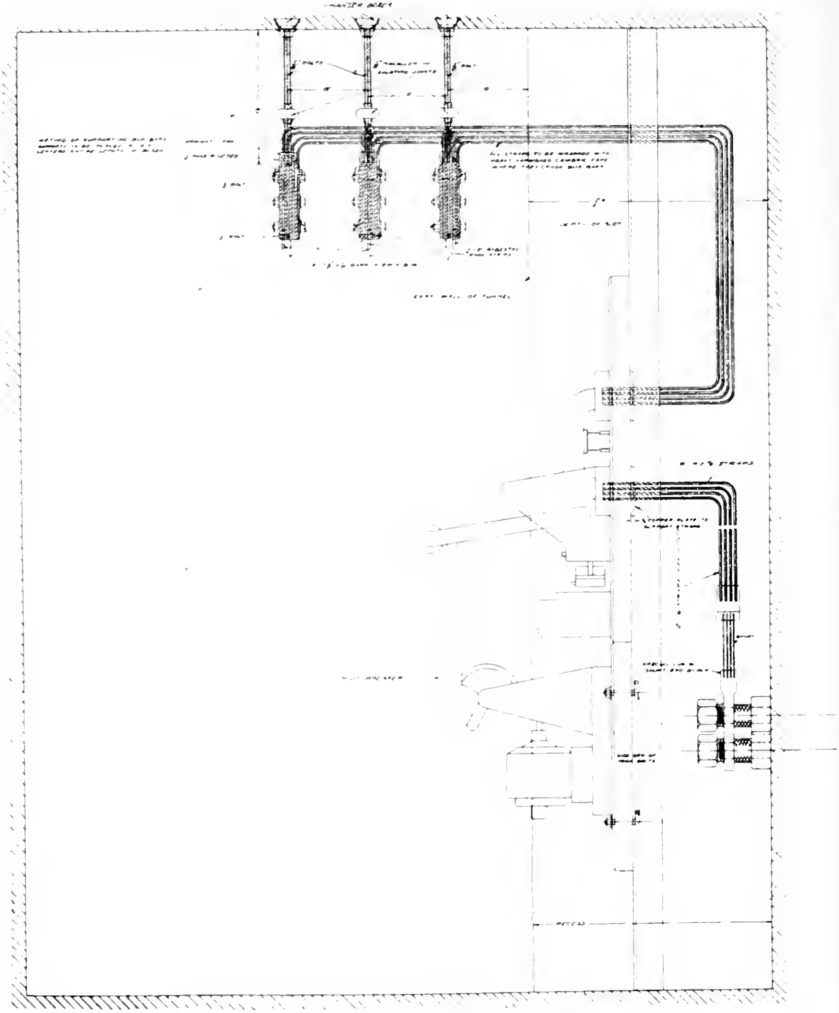


Fig. 101. Bus Bars and Connections.

The boards are built of slate with "satin" finish, are equipped with Walker switches, Weston instruments, Sangamo watt meters, and General Electric contactors and relays.

That some idea may be had of the heavy copper bus-bar work, and the method used for connecting machine circuit-breakers to the busses, a detail is shown in Fig. 101. The bars are dropped sufficiently from the ceiling to secure circulation of air, and are supported by Macallen insulating joints.

Distribution: The system of wiring is 230-volt, two-wire for transmission and for power service, with three-wire, 220/110/110 distribution for the lighting feeders and mains, which are carried in the usual manner to cutout cabinets from which centers the tap circuits are led to the lights.

The power and lighting service is furnished to the main building through twelve 2,000,000 circular mil cables carried in space below the pipe runway. Fig. 102 shows the manner in which the trainshed roof-girders were drilled, there being three rows of four holes, each 3 in. in diameter. At each side of the beam below each row of cable holes, 2 in. by 4 in. asbestos board supports were bolted. Intermediate supports for the cables were made up in the manner shown in the figure, there being two of these supports between each bent at about 8 ft. centers. This arrangement of supports with cables pulled up would bring a strain on each cable of approximately 500 lbs., or three tons' pull at each end of the run. As a means of securing the cables at the ends, a 2-in. asbestos board with 3-in. holes drilled so as to register with the holes in the girder was placed against the web, and after the cable was pulled up the insulation was stripped and a standard bolted 2-in. shaft coupling clamped to the cable, thus firmly securing the cables and permitting a minimum amount of sag between supports. These couplings are thoroughly taped after being placed in position and connections made to the rubber-covered conductors which are carried in conduit from

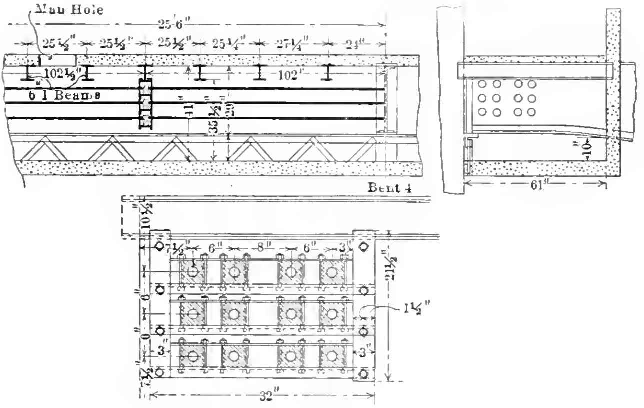


Fig. 102. Location of 12 Heavy Electric Cables for Light and Power.

the power-house to the north end of the cableway, and from the south end to the switchboard in the basement of the building.

Of the twelve cables for light and power service, four are connected through double-pole switches to the main lighting busses, clearly shown in the rear view of the board, Fig. 100. Two of the cables are connected directly through a double-pole switch with the power busses. Two are connected through a double-pole switch with the train-lighting busses, and the remaining four cables are connected each to a separate plate on the front of the switchboard, this plate being the base of two single-pole knife-blade switches. An inspection of the illustration shows that the arrangement permits of one of these cables being thrown either to the lighting or the train-lighting busses on either the positive or negative side. Likewise the other two cables, or either one of them, can be thrown upon the lighting busses or the power busses, or one on to the light and the other on to the power. By closing both of these switches, the power bus and the lighting bus are connected. The same applies to the lighting and the train-lighting busses.

From this description and by an inspection of the switchboard drawing, it can readily be seen that all manner of combinations can be made, and that by the manipulation of the feeder switches splendid regulation can be had. This is not at all complicated, as might seem at first glance, but when it is considered that the indirect lights in the Main Waiting Room are turned on only at certain times of the day and have an independent circuit, likewise the train lighting, not being required excepting in the evening, it is possible to simply cut out these two or three feeder circuits during the daytime.

A view of one of the cutout cabinets is shown in Fig. 103, that an idea may be had of the manner in which the remote-control switches governing the lighting are placed. The box shown is one of two on the south wall of the Main Concourse. A tap circuit is run from each of the fused knife-blade switches shown, and the arrangement is such that any one of the three or all of the remote-control switches shown can be closed by a push-button switch in the Information Bureau on the Main Waiting Room floor and thus connect all of the circuits that may be controlled by this switch. From this Information Bureau all the lighting throughout the Main Waiting Room, Concourse and the train shed platform lights are controlled. From the Information Bureau in the public space on the ground-level floor all public lights on the first floor of the building are controlled, as well as all the street lamps as far north as Lake street, and all subway lighting. It is therefore readily seen that the greater portion of the illumination throughout the Terminal is remotely controlled.

The Main Waiting Room lights are controlled in sections, the circuits being so divided as to permit partial lighting at such times as the entire illumination is not required. For instance, each ledge is divided into two sections, each section being controlled by two push-button switches. This allows of but one-half of the ledge lights to be turned on, or all of them, as desired; likewise the hanging fixtures and the standards, the fixtures being so arranged that the switches will throw on only the upper lights or the lower row of lights as desired. This same applies to the Main Concourse ceiling fixtures.

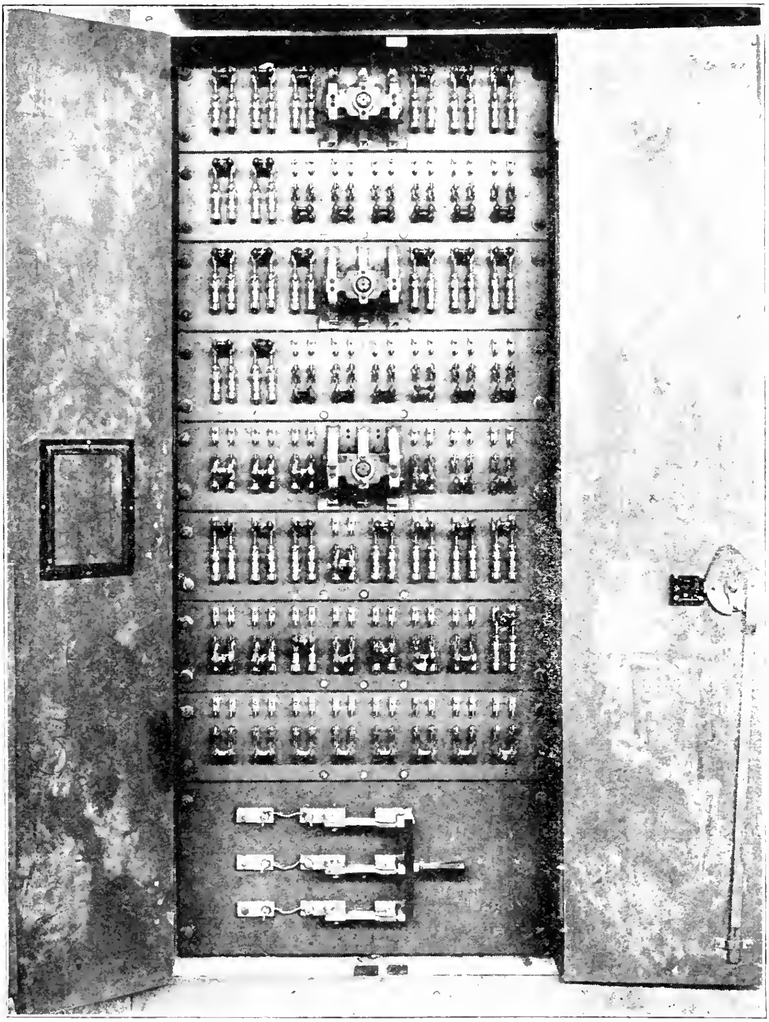


Fig. 103. Cutout Cabinet.

Pressure wires are brought from the centers back to the main building and power-house switchboard. For the purpose of maintaining a record of the voltages at the power-house lighting busses and at the main building lighting busses, an Esterline graphic recording voltmeter was placed at each point. These instruments simultaneously record the voltage, and serve as a means of comparison for different days with various load conditions. The two charts can be fastened together and thus the drop at any instant can be readily determined by inspection.

LIGHTING.

The Terminal station building proper is lighted throughout with Tungsten lamps. These with but few exceptions are 150 or 250-watt units. In small rooms and stairways, telephone booths, etc., the lamps are 40 watts or 60 watts, depending upon the space to be lighted.

The public space on the ground-floor level and the Main Waiting Room on the track-level floor, with the Train Concourse, are the most brilliantly lighted rooms in any railway terminal or public institution in the world. The lighting is evenly distributed, is without glare, and at the same time is entirely devoid of theatrical effects, and yet, while brilliant, it is of that peculiar softness which is not tiresome to the eyes. This remarkable effect is due to the combination of Tungsten units with the special glassware, together with the reflecting surface for the concealed lights.

The fixtures in the public space are extremely simple, consisting of a ring or crown holding 18-in. diameter white opal globes, one being placed in the ceiling of each bay and containing four 100-watt lamps, these lamps being arranged on two circuits so that when occasion does not require all of the lamps to burn, 50% of the lighting can be cut out, the system being further divided so that various sections of the room can be turned on or off as requirements demand.

The Main Waiting Room is to a very great extent illuminated by indirect lighting, these lights being placed on the ledges running along the north and south sides of the room at an elevation of 46 ft. above the floor. The ledges are 10 ft. wide. Each ledge is divided into seven spaces by the arches supporting the barrel roof, and in each of these sections there are thirty 250-watt lamps, each with its 250-watt Alba shade set at the proper angle to obtain the greatest amount of reflected light from the ceiling. The lamps and globes shown in Fig. 104 are mounted on a special frame designed for this particular purpose, being adjusted so as to vary the angle at which the light strikes the ceiling, which at its highest point is 84 ft. above the floor line. There is a total on both ledges of 420 lamps, being the equivalent of about 80,000 candle power.

Supplementing the indirect lighting, fixtures hang from the soffits between the columns of both the north and south sides, which can be seen in Fig. 105. At each of the east and west ends of the room are placed four large lighting standards; each contains about 1,880 candle power, made up of lamps varying in size from 100 watts to 150 watts. The soffit fixtures are practically the same. The effect of the indirect lighting as reflected from guastavino tile ceiling is quite pleasing and satisfying.

With but few exceptions throughout the building, the lighting is direct. Special treatment, however, has been given to the Dining Room, the Women's Waiting Room, and the Women's Tea Room, where indirect or reflected lighting is used, this giving a soft, evenly-distributed light throughout, but of somewhat less intensity than if direct lighting was used.

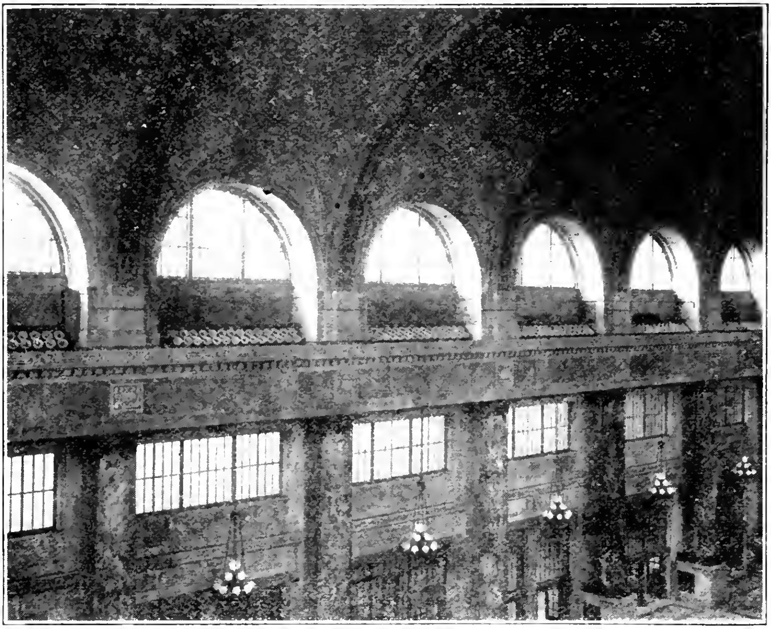


Fig. 104. Indirect Lighting of Main Waiting Room.

The barber shop on the track-level floor has been provided with indirect lights in the ceiling, while direct lighting has been placed in front of the mirrors, as well as bracket lights along the wall, the arrangement being such as to keep the direct rays out of line of vision of any one in the barber chairs.

Throughout, where direct lighting is used, Alba globes or Alba deep-bowl pattern shades are used, with but few exceptions, such as in the corridors in the office portion of the building, where the diffusing Alba shade is installed.

In the Madison street vestibule the lighting is indirect. The standards on the stairways are fitted with beautifully carved alabaster bowls. The indirect fixtures in the Dining Room and Women's Room are fitted with deep-bowl Alba shades arranged to throw the light upward to the ceiling.

In connection with the lighting, there is one point that deserves particular comment, and that is the special fixtures designed and installed for throwing light directly on to the stair landings. These boxes are set flush with the wall, and each contains a linolite lamp with aluminum reflector and glass front. These are set near the floor of the stair landings. Since the station has been opened, it has been found that this lighting is quite sufficient, without the use of bracket lights, to illuminate all of the minor stair cases throughout the building, not only throwing enough light upon the landing, but sufficient being cast upon the walls to perfectly light the stairway.

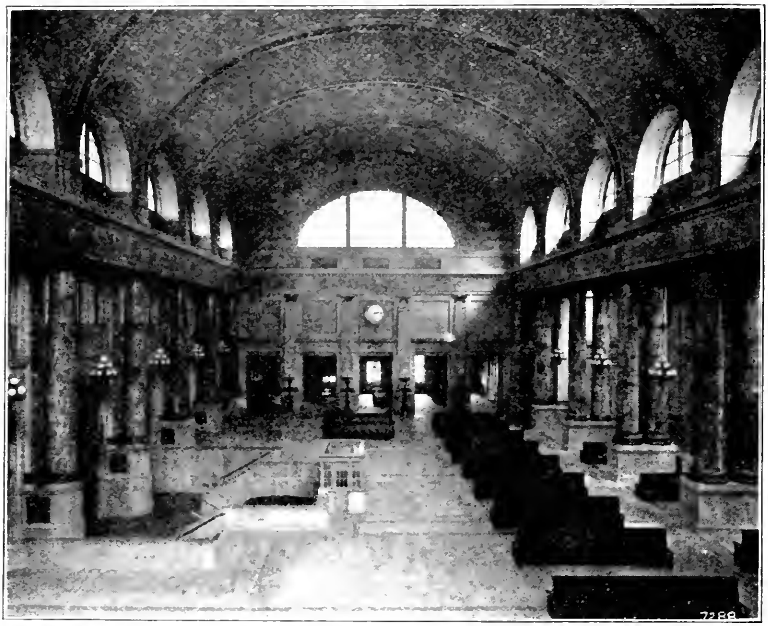


Fig. 105. Main Waiting Room—Lighting.

Special fixtures were designed by the engineers for lighting the basement, the baggage-storage room under the Main Concourse, and the incoming-baggage room on the ground-level floor.

These are made up with a substantially designed shock absorber, plain conduit stem with spun zinc canopy and cast zinc weather-proof socket, each being equipped, with but few exceptions, with a large 250-watt Alba shade. A single unit was placed in each bay as near as the steel construction would permit, and the results are quite satisfactory.

The under-track portion is lighted throughout in the same manner as the basement of the Terminal station building, 250-watt shades being used, with the exception of such places as carriage driveways and automobile space, where 100-watt lamps are used. Likewise the subways are equipped with the same class of fixtures, and with 100-watt lamps and shades. These subway fixtures are also further provided with guards which were made specially for this installation, the guard being so designed as to cover the entire shade, being hinged at the top and fastened at the bottom with small Yale lock clamping two heavy No. 12 wire rings. These guards serve the double purpose of preventing lamps from being stolen and avoiding breakage of lamps and shades by teamsters' whips. The same protection has been provided for lamps and shades in under-track and public spaces, such as driveways and in express, baggage and mail rooms.

Special attention has been given to street lighting, the architects having designed special posts or standards, those on the Madison street front of the building being quite ornamental in design, while those for sidewalk lighting on Canal and Clinton streets and Milwaukee avenue are of a simpler design, but artistic. The four large standards in front of the Terminal each contain thirteen lights, three 150-watt lamps being placed in the top 30-in. globe and 100-watt lamps in each of the four others, the two lower globes each containing three 60-watt lamps, making a total of 1,210 watts. The other street posts are equipped with three 60-watt lamps in a 20-in. Alba globe for the top, while each of the three brackets from which the 12-in. lamp globes hang contain one 60-watt lamp, making a total of 360 watts per post. In all, there are 53 street lamp posts in addition to the four large standards.

For the Washington street subway 43 lamps are provided, either 19, 24, or all of which can be used as necessity requires; likewise Randolph street, 26 lamps, evenly divided; Lake street, 14 lamps, divided into 6 and 8; and Milwaukee avenue, 9 lamps, divided into 4 and 5.

The Post Office is cared for, so far as general illumination is concerned, in practically the same manner as all other under-track portions, but in addition, small 12-volt Tungsten lamps, nine in series, are installed over the sorting cases. Some Cooper-Hewitt lamps have been installed in certain portions in part of the Post Office quarters, but a majority have been hung in the driveway.

Each of the towers for the Main Building contains a clock dial 10 ft. in diameter. There are also other clocks of about the same size on the train-shed walls, one each over the east and west entrances at Washington street. All clock dials are electrically illuminated with 24-carbon filament, 16 c. p. lamps. The lamps are placed behind the dials and arranged upon a ring with a white enamel steel reflector back of the lamps, the ring being supported in such a manner as to revolve so that any of the lamps can be reached by one standing on the floor.

Carefully designed equipment has been provided for the lighting of trains standing in the train sheds. At the end of each track there are one or more train reels suspended overhead and containing a length of insulated, very flexible cable connected with the 220 110-volt train-lighting busses of the switchboard in the basement of the building. (See Fig. 106.) One end of these cables is provided with a suitable plug to be inserted in the train receptacle provided with the car wiring. Inasmuch as this train-lighting is on the three-wire system, an arrangement has been installed for the purpose of detecting any unbalancing. This is in the form of ammeter stands placed between the bumpers at the end of each pair of tracks, these stands being provided with small Weston instruments connected in such a way as to show by the deflection of the pointer whether any particular train being supplied with energy causes an unbalancing of the system. This will always show an unbalance of approximately 25 kw. when there is an odd number of trains. Otherwise the point should be at or

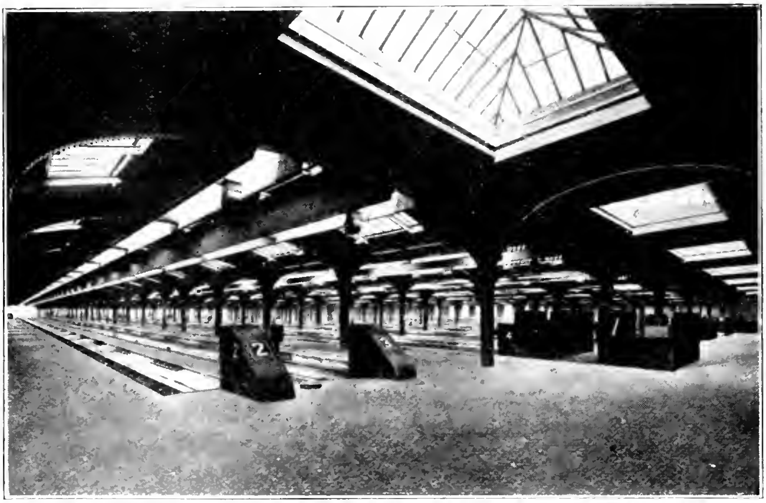


Fig. 106. Train Shed.

near zero, as when there are two or four trains on the track, the amount of current required by each one is more or less the same and the system would be practically balanced. In case of an even number of trains being served and the instrument indicates an unbalancing of 50 kw., or somewhere in that neighborhood, the connections are changed by simple push-button switches which will operate remote-control switches so arranged as to put any one or more trains on the opposite side of the three-wire system and thus balance it up. One of these stands can be seen between bumpers 2 and 3, in Fig. 106.

The total wattage of the lamps called for by the present installation amounts to 546.753. It might be well to mention here that the total motor installation at the present time is equivalent to 701,700 watts, and that the service furnished to the interlocking towers amounts to 90,000 watts. Poles have been installed and lamps will shortly be placed for yard lighting to the extent of 7,200 watts. The grand total at the present time is practically 1,375 kilowatts. In addition to this, the future requirements which the machinery is installed to care for, are such items as the subway lighting north of Milwaukee avenue to the extent of 200 kw.; certain of the railway yards, 350 kw., or 550 kw. The total requirements, therefore, are 1,925 kw. for the lighting and motor requirements, while there will be 150 kw. additional for train lighting, or 2,075 kw.

A cross-sectional view of the Main Building is given in Fig. 107. This shows the street lamp posts, the lighting fixtures in the Madison street vestibule, in the public space on the first floor, in the Main Waiting Room on the track-level floor, also the Main Concourse, the inlet registers for ventilation of the Main Waiting Room, as well as the skylights, to which exhaust fans are connected. The elevator pumping engines are shown in the basement.

MOTOR APPLICATIONS.

There is at the present time approximately 950 h. p. in motors installed throughout the Terminal. These perform various services, from the 75 h. p. motor driving the centrifugal circulating pump in the power-house down to the small 1½ h. p. motors driving knife polishers and smaller machines used in connection with the restaurant kitchen, while the Post Office has several ½ and ¾ h. p. motors.

The ten electric elevators are each equipped with a 25 h. p. motor. The three dumb-waiters in the main building are each equipped with a 5 h. p. motor.

ECONOMIC RESULTS.

The Corliss engines in the power-house are guaranteed to develop an indicated horse-power on 18.6 lbs. of steam per hour

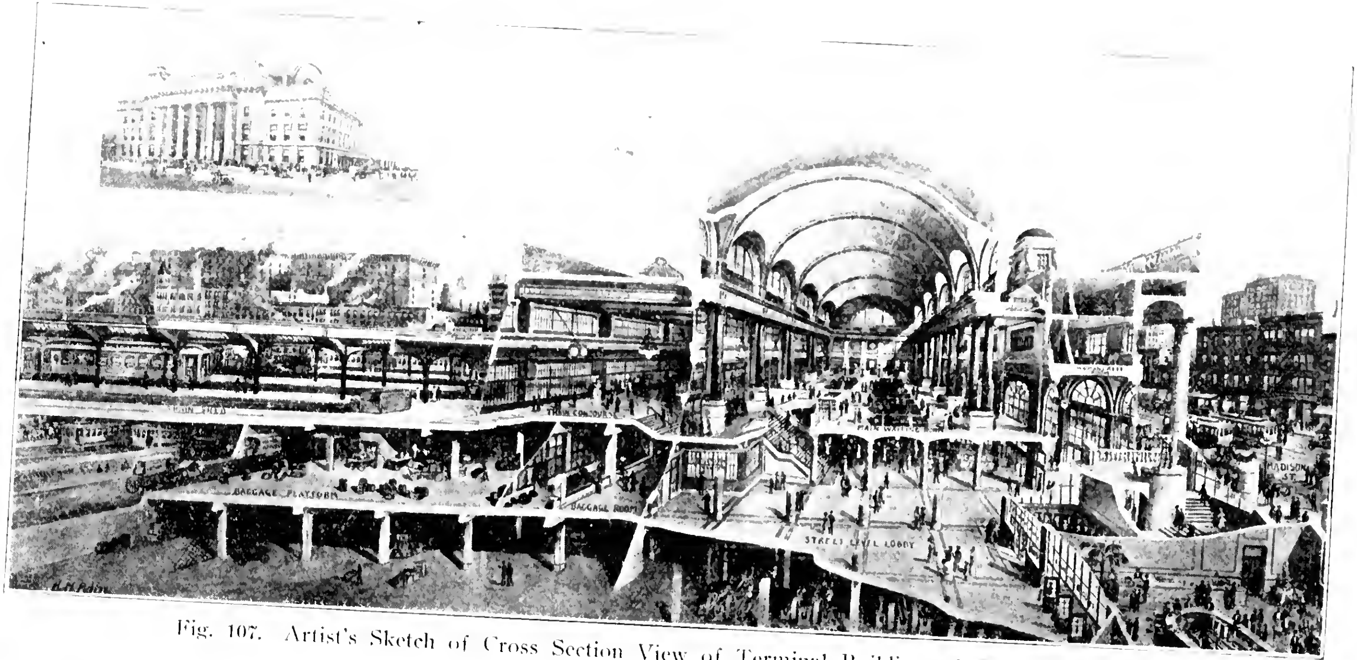


Fig. 107. Artist's Sketch of Cross Section View of Terminal Building of C. & N.-W. Ry.

when running at full load, with 1½ lbs. back pressure or 16½ lbs. absolute back pressure.

The total amount of steam required for each engine unit with full load of 1,150 i. h. p. will, therefore, be 21,400 lbs. exhausted to the low-pressure turbine. This turbine has been installed under a guarantee to deliver a kw. hour on 43½ lbs. of exhaust steam at a pressure of 16½ lbs. absolute, with a vacuum of 27 in., or a horse-power on 32.7 lbs. Utilizing all of the 21,400 lbs. of steam exhausted from one engine unit, the turbine will develop an additional 786 h. p., or there will be a total of 1,936 h. p. for the combined engine and turbine units, or a horse-power hour on 11.8 lbs. of steam. This is a somewhat unusual performance, specially when it is considered that over 40% of that developed is in actual delivered horse-power with the balance of 60% as "indicated."

Comparing the performance with that of high-pressure turbines of 1,000 kw. capacity operating under the same steam and vacuum conditions, attention is directed to the fact that the machinery installed will develop 1,250 kw. on 21,400 lbs. of steam, or a kw. hour on 17.1 lbs. of steam, while with the high-pressure turbines the best that can be guaranteed is slightly below 22 lbs. of steam per kw. hour. The advantage of the combined reciprocating engine and turbine units is readily appreciated when it is seen that they net some 250 kw. in addition to that developed by a high-pressure turbine unit of the same size and using the same amount of steam under the same conditions of pressure, superheat, and vacuum, and the turbine actually delivering a kw. hour on 21.4 lbs. of steam. To show the advantage of the system adopted, it is unnecessary to consider the auxiliaries, as the pounds of exhaust in either case would be the same, and with the same output of 1,250 kw. all items will be against the high-pressure turbine performance.

The engine performance will naturally be best at full load, but when operating uneconomically at light loads, the excess steam required per unit of output is more than balanced by the increased output of the turbine, which brings the combined economy up to a high point.

A typical load curve of August 9, 1911, is produced in Fig. 108 for the purpose of showing the manner in which the turbine divides the load with the engine unit. The average percentage of the total load taken by the turbine, as shown by this curve, is substantially 46%; in other words, the turbine and the generator practically divide the load. This result is in a large measure due to the fact of its being possible to utilize exhaust from air compressors and other steam-using apparatus. It thus appears that about 50% of the total station load is developed by the use of exhaust steam from miscellaneous apparatus.

The turbine under all conditions takes the fluctuations in load to such an extent as the conditions of exhaust steam will permit. It can thus readily be seen that there are features about this installation which make strongly for economical production of electrical energy, especially as the plant of necessity is a mixed one, where air compressors and other steam-actuated apparatus exhaust into the line so that it can be utilized in the exhaust steam turbine. As

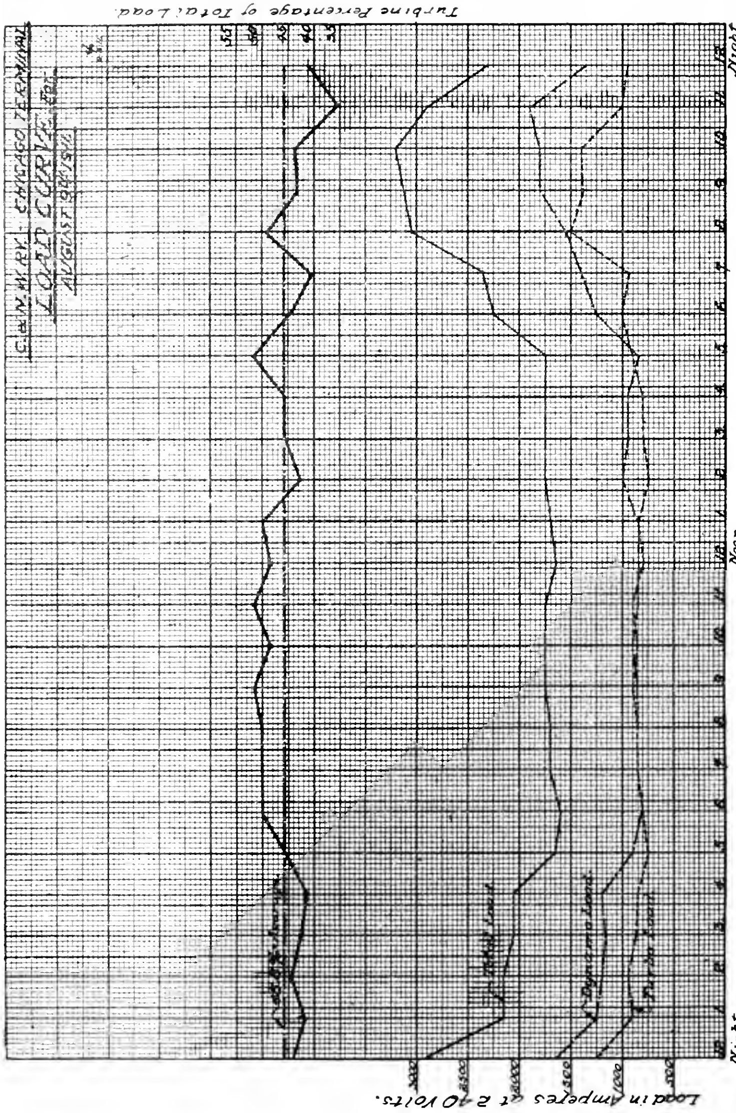


Fig. 108. Typical Load Curve, August 9, 1911.

near as can be determined from the short period the plant has been in service, there is delivered to the turbine sufficient exhaust steam from the elevator pumping units alone to realize an additional 10 kw. capacity from the turbine, while with one air compressor in service the output is increased by approximately 60 kw.

One interesting point in the economical operation of the plant is the fact that the only city water used at the present time is that flowing through the jackets, in the intercooler and aftercooler of the air compressors, with that from the water-cooled guides and main bearings of the engines, as well as that from the turbine bearings, which water is collected in a tank, and by the make-up pump is forced to the cooling tower. This is sufficient to make up for the evaporation losses in the tower and permits of the utilization of jacket cooling water, a great portion of which would otherwise go to waste.

Another feature which has been brought to notice since the plant was placed in operation is that there is no loss of steam in starting up a second engine, as the exhaust steam from this unit is used by the turbine. It is evident from this that with the combination of the non-condensing engine units with the condensing low-pressure turbine, there is not the loss of steam that is always incident to a straight high-pressure turbine installation where considerable steam is used to warm up the machine.

It will be noted by reference to the chart for the recording thermometer that the temperature of the water in the feed water heater is maintained between 195 deg. and 200 deg. F. The feed water heater being of the induction type renders it possible to accomplish this result, thus using only what steam the heater requires, allowing the balance to go to the turbine. One of the temperature recording thermometer charts is shown in Fig. 109, while in Fig. 110 a chart of boiler pressures is shown.

For the purpose of checking the original calculations as to cost of producing a kw. hour, careful observations were made and records kept of operating conditions and costs. The present load on the plant is but 50% of that to be cared for in the immediate future, and even while this paper is in preparation these additions are in progress.

The plant is now producing power at the rate of 4,320,000 kw. hours per year. The actual cost is but 1.975c per kw. hour, including fuel, labor, and the interest, insurance, taxes, and depreciation on the cost of machinery and building. With double the load, or 8,640,000 kw. hours per year, the cost per kw. hour will be but 1.099c. In inspecting these figures the fact must not be lost sight of that the items of labor and the overhead charges cover attendants who care for machinery other than that used in the generation or utilization of electrical energy. The fixed expenses cover the cost of the building housing miscellaneous apparatus not incident to the electrical plant, and no deduction in the cost of boiler equipment is made for such portion as may fairly be charged to the requirements of such other apparatus.

The cost of generation of steam for purely heating purposes should be credited to the production cost per kilowatt hour, inasmuch as exhaust steam will be utilized for this purpose. This credit properly made brings the cost per kilowatt hour to *less than one cent* when developing the 8,640,000 kw. hours per year.

All of the above figures are substantiated by the operating results thus far obtained, and, while the results are specially favorable, it must be remembered that the heating demands are considerable, and that the fuel cost is low. The *actual* cost of the fuel is about 40% below that used in the computations as it comes from the railway company's own mines, and the market price of the fuel is charged against the kw. cost as used rather than the real cost to the company.

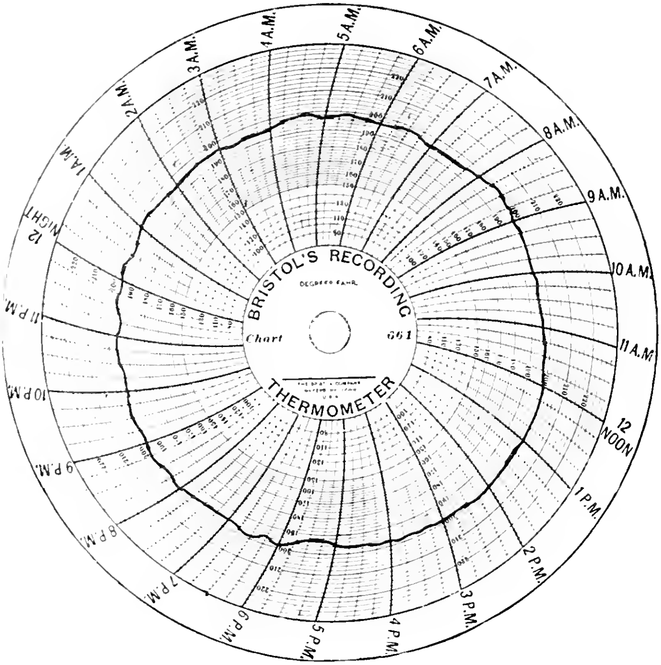


Fig. 109. Temperature Recording Chart.

As a matter of peculiar interest, attention is called to the cost of current as produced at the present time by the low-pressure turbine. It was found by actual test that under a two weeks' operation without the turbine, the fuel consumption was increased by ten tons of coal per day of 24 hours. The unit was put in service and at once the fuel requirement decreased by the ten tons, and this when the machine was only developing some 240 kw., of which 60 kw. was used in driving auxiliaries. With this small net load of 180 kw. for 24 hours per day, and the turbine operating but 200 days in the year, there will be netted a total of 864.000 kw. hours. Now, deducting the saving in fuel cost for 200 days, from the fixed charges due to turbine and condensing apparatus, with its cooling tower, there is left the amount of $1,120.00. Thus the actual cost is but 0.13c per kw. hour. As the turbine is run at greater load or for a longer number of days, the savings will more nearly equal the investment charges. For example, with a net load of 440 kw., the cost per kilowatt hour will equal but 0.05c, and this will be but everyday practice when the projects now in contemplation, calling for increased output, are completed.

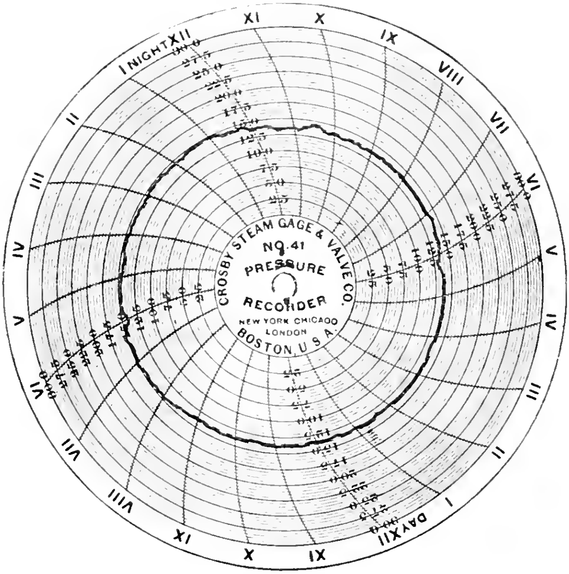


Fig. 110. Recording Chart of Boiler Pressure.

The present plant capacity is 2,750 kw., with space arranged for a future 750 kw. engine driven unit and a 500 kw. turbine and generator unit, making in all 4,000 kw. The future turbine will in all proability be A. C., as such a machine can then be used as a relay to the present A. C. motor-generator sets, and in case of emergency could be used to drive one motor-generator set reversed, delivering D. C. current to the station busses. Such a unit would be in the nature of a double relay—a very desirable feature and one which would save a certain amount of duplication.

CONCLUSION.

Pierce, Richardson & Neiler were the consulting and designing engineers, having charge of all the electrical and mechanical work for the architects, Messrs. Frost & Granger. All matters pertaining to the engineering problems were considered in committee meetings. The larger questions involved and many of the important details were given personal consideration by Marvin Hughitt, president of the railway at the time.

The entire work was formulated and carried out under the direct instructions of John Whitman, Vice President, and Edward C. Carter, Chief Engineer of the railway company. In the selection of machinery and apparatus for the power-house, R. Quayle, Superintendent of Motive Power and Machinery, was freely consulted; and in matters pertaining to construction details affecting this work, the engineers were afforded all possible assistance by W. C. Armstrong, Terminal Engineer. In such work as was done in connection with the signaling system and interlocking towers, the engineers advised with J. A. Peabody, Signal Engineer, as they also did with A. J. Farrelly, Electrical Engineer, in regard to the lighting and the requirements in general.

This description of the Terminal station would not be complete without credit being given to those who worked with the author in the design and execution of the various engineering features involved:

Mr. H. A. Robinson had charge of the ventilation and the electrical system of distribution, and, due to his foresight and engineering ability, perfect ventilation was secured and the splendid illuminating effects were possible.

Under the direction of Mr. Edward P. Rich, the heating transmission and the details and arrangements of the power-house piping were designed and carried out.

The checking and superintending of the work in accordance with the designs were well cared for by Mr. J. S. Jenson, as regards ventilation and lighting; and by Mr. E. N. Clingman, in connection with the switchboard and A. C. work.

The author was in direct charge of all branches of the work.

While the consulting engineers designed and directed the entire installation, the successful operation is due, in no small measure, to the co-operation of the contractors, whose unflagging interest and fidelity has permitted a satisfactory termination of the work. And, what is of greater value, is the thoroughness with which the details of the various portions of the work were executed, thus rendering possible the starting up of the entire machinery plants, with transmissions and distributing systems, without the slightest sign of trouble whatever.

Looking back over the period from inception to completion, it is a pleasure to recall that with the settling of all the questions involved, and the immense amount of detail gone over, there was not a single dissension. The architects, the engineers, and the railway officials all worked in perfect harmony, and with but one purpose in view—for the making of a great railway terminal complete in every essential detail. This they have unqualifiedly accomplished.

Discussion.

G. T. Seely, M. W. S. E. (Chairman): The paper this evening is the third in the series of three papers on the New North Western Terminal. The first was by Mr. W. C. Armstrong, Vice-President of this society, describing the general constructive features of the Terminal, and the reason for building it as they did and where they did. The second was by Mr. J. A. Peabody, Signal Engineer of the C. & N. W. Ry. Co., and describes the signaling and interlocking of the Terminal. The third paper is that presented this evening on the electrical and mechanical equipment of the Terminal, by Mr. S. G. Neiler, who was the consulting engineer in charge of the mechanical and electrical features. I make this explanation for the benefit of the members of the American Institute of Electrical Engineers.

The traveler who uses this station can have no conception of the great amount of apparatus that is necessary for the operation of a successful Terminal of this kind. Any one who has followed the papers which have been given on this Terminal, is deeply impressed with the great amount of thought and study that have been given to each detail of the many problems that confronted the engineers who had charge of it. It seems that no expense has been spared to furnish every device that will make travel through this station comfortable, safe, and expeditious.

A. Bement, M. W. S. E.: There are two features of which I will speak. One concerns the lighting; the other the boilers in the power plant.

I would call atention to lighting in the vestibule of the main entrance. At the stairway landing are located fixtures mounting concealed lamps in alabaster bowls. The result is a complete and ideal diffusion. Light emanates from the bowls so that it is difficult to determine where the lamps are located. This, I consider, is one of the most successful pieces of illuminating work, if not the best, ever devised, and is well worth a visit to the station.

With reference to the boiler plant, I am much gratified to see that self-feeding coal-spouts have been used. That is a device that I have believed in for a long time, and have advocated its use, but some of the efforts made for its employment in this locality have not been successful, due, no doubt, to not obtaining a correct design. I hope no difficulty has been experienced at this plant, and would ask Mr. Neiler if the spouts feed uniformally?

When we consider that the pushing of the straight coal-spout from side to side of the stoker hopper requires about one-half the labor employed in the regular operation of the boilers in a modern power-plant equipped with chain-grate stokers, then it is apparent that their use is of considerable value if they work properly. Not only is there a saving in labor, but the assurance of a full and continuous feed of coal to the stokers is in itself a matter of great advantage.

Referring to the boiler plant, I am interested to know about its behavior. The installation is the second of this type of setting, and since it was made, the manufacturer of the boiler has again changed to another design; so I suppose that this reversed setting will never be used again. Two reasons probably governed its adoption, requiring the stoker to be set under the low end of the boiler: The first was that the manufacturer did not want to employ the original suggestion for application of a tile roof, because it originated with some one else, and so set the boiler with the "back end at the front." The other reason is that there may have been fear that if the heat impinged first on the low end of the tubes, it would cause the boiler to "circulate backwards,"—a theory, however, which is purely imaginary. I observe that Mr. Neiler has not followed the design of the manufacturer in all particulars, and would ask if he made other departures from it than those mentioned. Also, what has been the behavior of the setting during the short time the boiler has been in use; what boiler horse-power is developed per boiler, the percent CO_2 realized, and the efficiency secured?

Mr. Neiler: Referring to Mr. Bement's questions. The settings are not enclosed in steel. They have a cast-iron plate on either side, running back as far as the bridge wall, and that is put there simply for the purpose of preventing the infiltration of air in case of a crack in the brickwork, which we so often find.

I do not know what action has taken place in the furnaces, as to whether the bridge walls are welded to the side walls or not; but I think Mr. Ravlin, who is chief engineer of the plant, can tell us about that.

F. J. Ravlin: The bridge walls are not welded to the furnace walls, and so far we have had no trouble of any kind with those settings.

Mr. Neiler: We have not had sufficient expansion, I know, to crack the walls, excepting some very small cracks in the rear, which we would naturally expect.

Frank F. Fowle: I have been impressed by the use of reciprocating engines and low-pressure turbines. One might expect, in a general way, in approaching a plant of this sort, to find high-pressure turbines; but undoubtedly the use of so much steam for other purposes settled this question, and brought about the decision for the reciprocating engines and low-pressure turbines.

A still larger aspect of this question, which interests me, is the fact that this is perhaps one of the largest and undoubtedly the most modern isolated plant in Chicago. In the beginning, the question probably arose as to whether it was economy to install an isolated plant or to purchase power from the public utility company. Of course, there are precedents here in Chicago for purchasing power in even larger quantities than are used in this plant; undoubtedly the surface roads, as well as the elevated roads, use a great deal more power than this plant requires. Some of the considerations that came up at that time, in the early stage of the problem, would be very interesting.

Mr. Neiler: Those considerations came up three years ago and they are not particularly vivid in my mind just at present; but the main point was, as I stated in the paper, that it was inadvisable to obtain condensing water from the river, so there was only one thing to do, and that was to put in non-condensing engines. The steam requirements for heating are such as to call for the exhaust of one engine running under full load conditions. If it runs under its guaranty of 18.6 pounds of steam per horsepower per hour, we would have about 22,000 odd pounds of exhaust steam per hour. That will take care of the heating in the coldest weather. We use but half that steam on the average. Therefore, we found that we could install an exhaust steam turbine with the cooling tower and not have as much vapor to throw out to the atmosphere as we would if we attempted to run the complete plant, which will eventually be 4,000 kw., as a condensing plant with cooling towers. We shall be enabled to utilize the exhaust steam for heating and other purposes for a portion of the year. The balance of the year we can save considerable money by running the exhaust steam turbine. In fact, with the turbine now, as we are running it, with only half a load, utilizing the exhaust steam available in the plant, we are producing a kilowatt hour at less than one-tenth of a cent, which is better, I believe, than anything that has ever been done before in any plant. I mention this because the turbine furnishes practically 50 per cent of the present power, and the fuel saving pays the greater part of the overhead charges on the investment of about $32,000.

The evaporation from the cooling tower on a full load will be about 33 gallons of water per minute. We can readily care for that amount, but should we try to take care of the total output of the station by the use of cooling towers, we would have to contend with considerable ice on the tracks. For this reason we have divided the plant as we have.

PROCEEDINGS OF THE SOCIETY

MINUTES OF THE MEETINGS.

Extra and Joint Meeting, November 22, 1911.

An extra meeting of the Society (No. 762), being a joint meeting of the Electrical Section, W. S. E., and the Chicago Section A. I. E. E., was held Wednesday evening, November 22, 1911.

The meeting was called to order at 8:30 p. m., with Mr. J. G. Wray presiding and about 65 members and guests in attendance.

The chairman introduced Mr. R. W. Pope, Honorary Secretary, A. I. E. E., who spoke a few words of greeting and good will, and expressed his interest in these joint meetings.

Announcement was made that the next joint meeting would be held December 27, 1911, when Mr. James Lyman, M. W. S. E., would present a paper on "The Protection of High Tension Power Circuits and Apparatus."

The chairman introduced Mr. F. F. Fowle, who read his paper on "Going Value," with some lantern-slide illustrations of diagrams and tables.

Discussion followed from Messrs. Benezette Williams and J. W. Alvord, past presidents W. S. E., M. G. Lloyd, W. D. Norton, J. R. Cravath, and the chairman, with a closure from Mr. Fowle.

The meeting adjourned at 11 p. m.

Extra Meeting, Wednesday, November 29, 1911.

An extra meeting of the Society (No. 763)—Ladies' Night—was held Wednesday evening, November 29. The meeting was called to order by President Chamberlain at 8:15 p. m., with 80 to 100 members and guests in attendance, including many ladies.

The president introduced Mr. Wm. Hoskins, M. W. S. E., who read his paper on "Forms of Water—Snow Crystals." This was illustrated by a number of beautiful stereopticon views of clouds, mists, fogs, running streams and waterfalls, as well as a large collection showing water in crystalline form, ice and snow crystals. After the lecture, refreshments were served.

The meeting adjourned about 10 p. m.

Regular Meeting, Wednesday, December 6, 1911.

A regular meeting of the Society (No. 764) was held Wednesday evening, December 6. The meeting was called to order by President Chamberlain at 8:25 p. m., with but a small attendance—less than 30 members and guests. The minutes of the postponed regular meeting, held November 15, were read and approved.

The Secretary reported from the Board of Direction that the following had applied for membership:

Norman M. Stineman, Chicago.
Tirrell J. Ferrenz, Chicago.
James Whiting Johnson, Chicago.
Edwin Wood Allen, Chicago.
Frank A. Randall, Chicago. Transfer.
Wirt Foster Smith, Chicago.
William Thomas Barnes, Chicago.
James E. Foss, Jr., Kahului, Maui, H. T.
Joseph B. Brady, Chicago.
Dwight B. Ball, Chicago.
Edward L. Lahey, Chicago. Transfer.
Perry Charles Mark, Chicago.

Also that the following had been elected into membership:

	Grade.
Harold Dean Bliss, Chicago	Junior Member
Lockwood James Towne, Lincoln, Neb.	Associate Member
Thomas Douglas Mylrea, Chicago	Junior Member
Fred E. Amthor, Gary, Ind.	Junior Member
Fred H. Burgess, St. Louis, Mo., transferred to	Associate Member
Willis George Frost, Ft. Atkinson, Wis.	Associate Member
Edwin J. Fowler, Chicago	Member

The award of the Chanute Medals for papers presented to the Society in 1910, based on the recommendations of the committee appointed for that purpose, was announced as follows:

Civil Engineering, to Charles K. Mohler, for his paper on Earth Pressures.

Mechanical Engineering, to C. P. Berg, for his paper on Heat Treatment of High Speed Tools.

Electrical Engineering, to H. B. Gear, for his paper on Diversity Factor in the Distribution of Electric Light and Power.

The Secretary reported from the Board of Direction the result of the canvass of petitions for nominations for officers of the Society for 1912, as follows:

President.

W. C. Armstrong and A. Reichmann.

First Vice-President.

A. Bement and C. R. Dart.

Second Vice-President.

G. T. Seely and O. E. Strehlow.

Third Vice-President.

John F. Hayford and E. C. Shankland.

Treasurer.

A. Reichmann.

Trustee for three years.

J. G. Giaver, B. E. Grant, and L. K. Sherman.

There being no further business, in the absence of the author—Prof. H. P. Boardman of the University of Nevada—the Secretary presented his paper on "Wind Pressures on Inclined Roofs." Contributions in discussion of this paper were submitted by Prof. Albert Smith, M. W. S. E., Purdue University; Prof. F. E. Nipher, of Washington University, St. Louis, Mo., and Prof. O. H. Basquin, M. W. S. E., of Northwestern University, Evanston. The latter illustrated his discussion by means of lantern slides and blackboard sketches.

The meeting adjourned about 9:30 p. m.

Extra Meeting, December 13, 1911.

An extra meeting of the Society (No. 765), being a meeting of the Bridge and Structural Section, was held Wednesday evening, December 13. The meeting was called to order at 8:20 p. m., Mr. John Brunner, M. W. S. E., presiding, and about 50 members and guests in attendance.

The minutes of the last meeting of the Section, held November 8, were read and approved.

The Chairman stated that the business of the meeting was the nomination of candidates for the Executive Committee for 1912. These nominations were made in writing, with Messrs. Reeves and Gibson as tellers.

The result was announced as follows:

For Chairman	F. E. Davidson
For Vice-Chairman	I. F. Stern
For two Directors	Wm. Artingstall
	C. W. Brooks
	J. G. Giaver
	J. H. Prior

The Secretary presented an amendment to the Rules of the Bridge and Structural Section, which had been submitted in writing by three members of the Section, as follows:

> "It is proposed to amend the Rules of the Bridge and Structural Section, so that the date of the regular meetings shall come on the same day of the week as that recently adopted for the regular meetings of the Society, as follows:
>
> "Amend paragraph 4 of the Rules by striking out the word 'Wednesday' and substituting therefor the word 'Monday' in the second line of said paragraph, so that it shall read as follows:
>
> "The regular meetings of the Bridge and Structural Section shall be held on the second Monday of each month," etc.
>
> (Signed, W. C. Armstrong, O. F. Dalstrom, Lee Jutton.)

The Chairman explained that this was to change the wording of the Rules of the Section to have the meetings held Monday evenings, instead of Wednesday evenings, as printed in the Year Book, 1911, to be in accord with the action of the Board of Direction of the Society, that meetings of the Society and Sections are to be held on Monday evenings after the first of January, 1912.

There were no amendments offered to this measure, and it was laid over until the January meeting, when it is to be put to vote.

There being no other business, the Chairman introduced Mr. O. F. Dalstrom, M. W. S. E., who read his paper on "Types of Shallow Floors for Railroad Bridges." Discussion followed from Messrs. I. F. Stern, Josiah Gibson, F. G. Vent, and Mr. Dalstrom.

Mr. Davidson was then called to the chair, as Mr. Brunner was obliged to leave. Mr. T. L. Condron was then introduced, who read a short paper on "Tests of Some Reinforced Concrete Floors of Large Buildings." This was illustrated by some lantern slide views. There was no discussion of this paper, and the meeting adjourned at 9:55 p. m.

Extra Meeting, December 20, 1911.

An extra meeting of the Society (No. 766) was held Wednesday evening, December 20, 1911. The meeting was called to order about 8:20 p. m. by President Chamberlain, with about 40 members and guests present. There was no business to bring before the Society, so the President introduced Mr. Robert R. McCormick, who addressed the meeting on the "Use of the Great Lakes."

At the request of the speaker the Secretary read from the *Engineering News* an abstract of an address by Prof. Gardner S. Williams before the National Irrigation Congress, held in Chicago about two weeks earlier, and treating of the same matter.

Discussion of Mr. McCormick's paper was offered by Messrs. G. M. Wisner, T. M. Sullivan, W. A. Evans, L. K. Sherman, W. L. Abbott, L. E. Cooley, A. Bement and H. S. Baker, with a closure from Mr. McCormick.

Meeting adjourned at 10:35 p. m.

Extra Meeting December 27, 1911.

An extra meeting of the society (No. 767), being a joint meeting of the Electrical Section W. S. E. and the Chicago Section A. I. E. E. was held Wednesday evening, December 27th.

The meeting was called to order at 8:15 p. m., Mr. G. T. Seely presiding, with about 75 members and guests in attendance. The minutes of the last preceding meeting of November 22nd were read and approved.

The secretary presented a petition for sundry amendments to the Rules of the Electrical Section, as follows:

> "Amend the Rules of the Electrical Section so that the date of the regular meetings of the Section shall come on the same day of the week as that recently adopted by the Board of Direction for the meetings of the Society.
>
> Amend paragraph 6 of the Rules by striking out the word Wednesday and substituting therefor the word Monday in the second line, of said paragraph, so that it will read: 'Regular meetings of the Electrical Section shall be held on the fourth Monday of each month,' etc.
>
> Amend paragraph 7 in a similar manner, and for a like purpose. so it will read: 'The annual meeting of the Section shall be held on the fourth Monday in January, for the purpose of canvassing the ballots,' etc.,
>
> Add to the Rules paragraph 10, making provision for amendments to these Rules, as follows:
>
> 10. Any amendment proposed to these Rules shall be reduced to writing, signed by at least three members, and presented at a regular meeting of the Section. It may then be amended and shall be voted upon at the next regular meeting of the Section. If adopted by a majority vote, it shall become effective."

The chairman announced that nominations were in order for members of the Executive Committee of the Section—namely, a Chairman, a Vice-Chairman, and one member of the committee to serve three years. On motion, a nominating committee was appointed, consisting of Messrs. Geo. H. Lukes, R. H. Rice and W. L. Abbott.

Mr. James Lyman then read his paper entitled, "Protection of High Tension Power Circuits and Apparatus." Some lantern slide illustrations were shown after reading the paper. Discussion followed from Messrs. R. F. Schuchardt, P. Junkersfeld, F. F. Fowle, W. L. Abbott, D. W. Roper, H. M. Wheeler, Alfred Herz, G. H. Lukes, D. Bowman, H. C. Dean, W. S. Monroe, A. Alsaker, H. B. Gear, with a closure from Mr. Lyman.

The report from the nominating committee was presented. The nominations were: Chairman, P. B. Woodworth; Vice-Chairman, James Lyman. Member of committee to serve three years, G. T. Seely.

The report was concurred in and the committee discharged.

The meeting adjourned about 10:30 p. m.

J. H. Warder,
Secretary.

BOOK REVIEWS

Electro-Analysis. By Edgar F. Smith, Blanchard Professor of Chemistry, University of Pennsylvania. P. Blakiston's Sons & Co., Philadelphia. Fifth ed., revised and enlarged, with 46 illustrations, 1911. Flexible leather; 7¼x5 in.; pp. 332, including index. Price, $2.50 net.

The work of Professor Smith is so well known that a new edition of his work on Electro-Chemistry will always be welcomed by chemists interested in analytical chemistry. The present edition contains as new material essentials of all that has appeared on electro-chemistry during the past four years; it includes a description of the devices, working tables, etc., in an electro-chemical laboratory. This is followed by an excellent historical sketch of the subject, theoretical consideration and methods for the rapid precipitation of metals in the electrolytic way, and the use of a mercury cathode. Chapters on the determination and separation of metals follow. The determinations of the halogens and nitric acid are described, as is also special application of the rotating anode and mercury cathode in analysis. Chapters on oxidation by means of the electric current and combustion of organic compounds complete the book. Numerous examples of the accuracy of the determinations and actual laboratory results are given. The methods and experiments are described with sufficient detail, and the book contains an excellent index. It is well printed on good paper and is serviceably bound. W. H.

THE NEW BUILDING ESTIMATOR. A handbook for Architects, Builders, Contractors, Appraisers, Engineers, Superintendents and Draftsmen, by Wm. Arthur. Published by David Williams Company, New York, N. Y. Cloth. 4½x6¼ in.; pp. 502; numerous tables. Price $2.50 postpaid.

The writer bought the first edition of Arthur's Building Estimator, and, having acquired the habit, has bought a copy of each succeeding edition; therefore it was with considerable pleasure that he undertook this review of the fifth edition. The author is a practical, hard-headed Scotchman who learned several trades connected with building work in Scotland. Coming to the United States he worked from the Atlantic coast to the Pacific and back again as far as Omaha, where he remained. Locally he has a great reputation as an estimator and lately served in the capacity for a state commission in Nebraska, getting fees for the work that would make the average engineer grow green with envy. Something of what he knows and has picked up about estimating he tries to give in his book, at present recognized as the best of its kind by practical builders. Like all books of cost data, it has many shortcomings, but it is practically impossible for a man who has a first-class knowledge of any particular subject like estimating, which requires the exercise of so much judgment, to write a perfect book. Estimators cannot be educated by reading books nor by studying books on cost data, but they all need such books. The author has a quaint way of expressing himself and the reader never knows when he is going to meet with a gem of Scotch wit. In telling how to take measurements for a certain material, he advises the reader to send a plan to the factory, for one plan is worth ten letters. He tells us he wrote the book because, after examining half a dozen other books, he concluded he could do better than had yet been done,—a frank confession not always made by authors. He advocates the making of estimates in a book and keeping it, for "the building may burn and the owner needs your help, or you may want to buy the building with your surplus profits, or may even be elected assessor." Again he says, "Do not accept any contract * * * unless you have plenty of money,—and if you have, why be a contractor"? The book contains data on everything in a building from the excavation to the putting on of wall paper. Nothing has been forgotten or omitted and the last chapter contains data on reinforced concrete in addition to the data on concrete in general in an earlier chapter. It is a book that all the men for whom it is intended should have, but it is not a book that can be referred to quickly as cost estimating is an art and not an exact science. This being true our Scotch friend cannot give us a book filled with tables and exact data, but must conduct us in his own easy interesting way through shorter cuts than he took to gain his information, yet not so short that we can get what we want without some twistings and turnings and pondering of data. The information he gives on depreciation is very good, and is often wanted by engineers. E. McC.

ⲔVI. No. 10. Dec., 1911.
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Plate I

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Western Society of Engineers.
Vol XVI. No. 10. Dec., 1911.
Armstrong—The New Passenger Terminal of the Chicago and North Western Railway

Plate I

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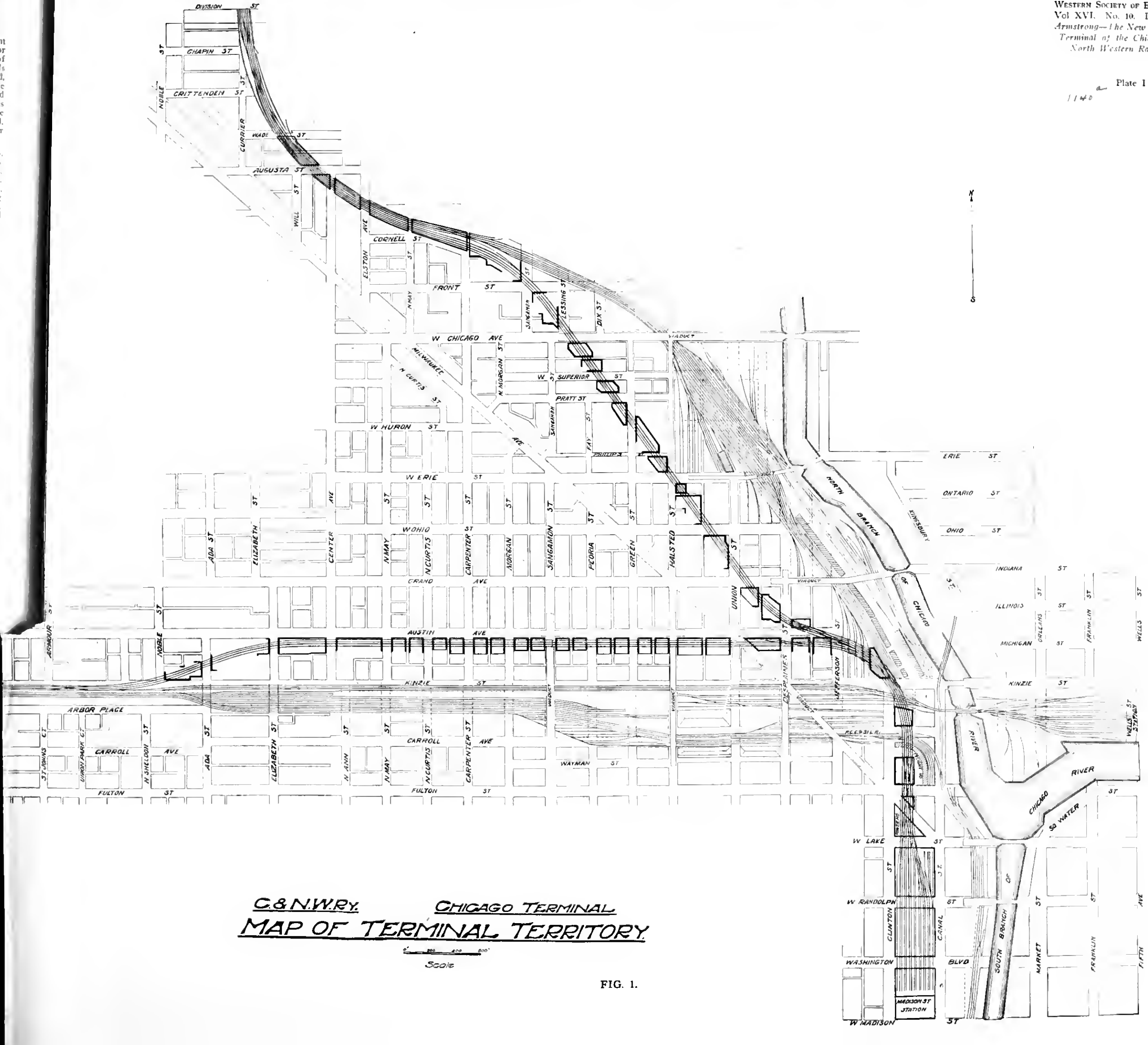

FIG. 1.

WESTERN SOCIETY OF ENGINEERS.
Vol XVI. No. 10. Dec., 1911.
Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

Plate II

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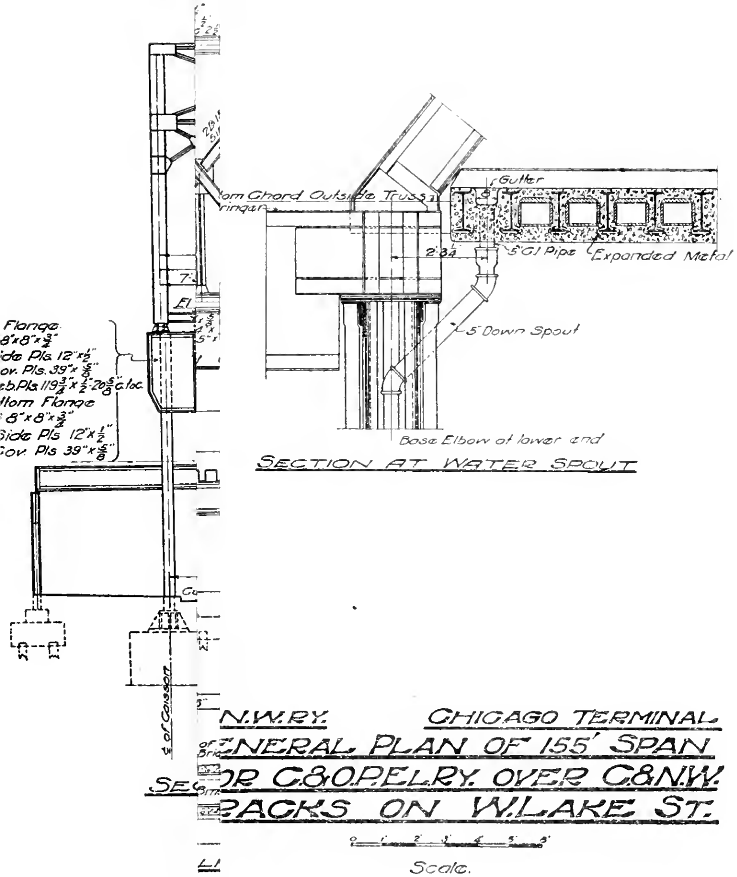


Western Society of Engineers
Vol XVI. No. 10. Dec., 1911.
Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

Plate II

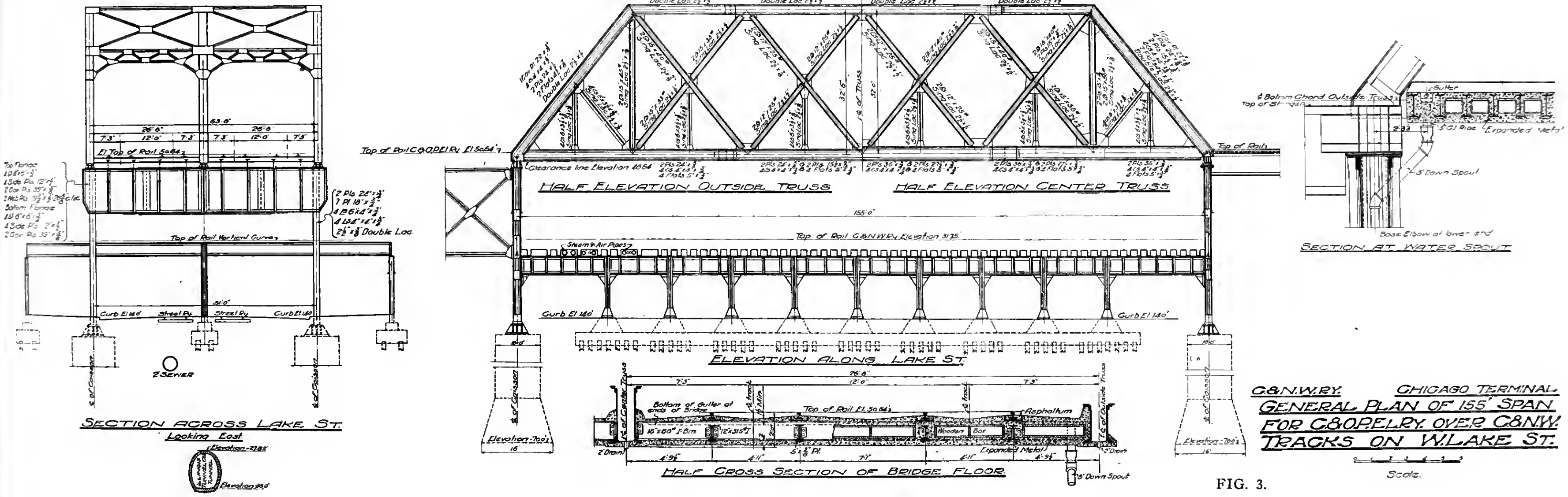
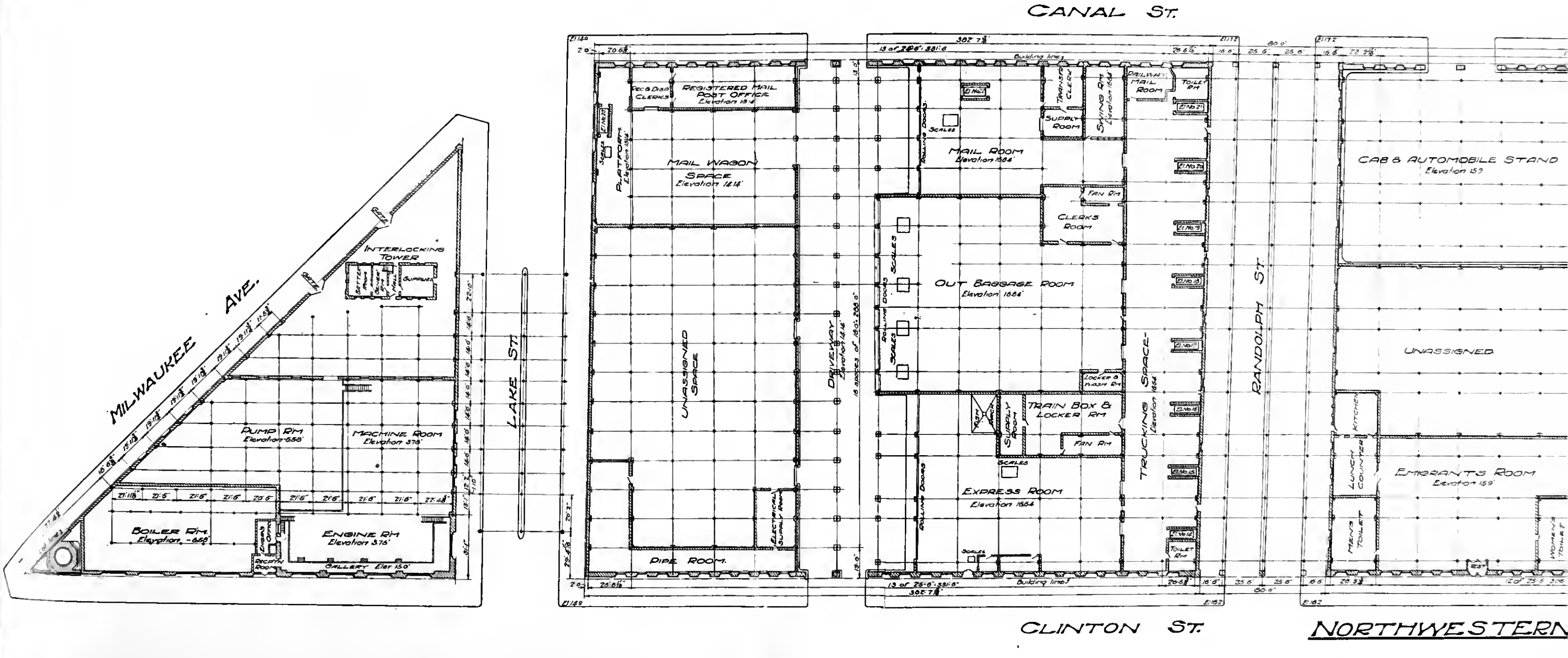


FIG. 3.


CANAL ST.
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LAKE ST.
RANDOLPH ST.
INTERLOCKING TOWER
SUPPLIES
PUMP RM
Elevation -6.58'
MACHINE ROOM
Elevation 3.76'
BOILER RM.
Elevation -6.58'
ENGINE RM
Elevation 3.76'
GALLERY Elev 15.0'
RECPT'N ROOM
REC & DISP CLERKS
REGISTERED MAIL POST OFFICE
Elevation 18.14'
PLATFORM
Elevation 18.14'
SCALES
MAIL WAGON SPACE
Elevation 18.14'
UNASSIGNED SPACE
ELECTRICAL SUPPLY ROOM
PIPE ROOM
DRIVEWAY
Elevation 18.14'
18 spaces of 18.0' = 288.0'
Building line
ROLLING DOORS
MAIL ROOM
Elevation 18.84'
TRANSFER CLERK
SUPPLY ROOM
SWING RM
RAILWAY MAIL ROOM
TOILET RM
FAN RM
CLERKS ROOM
OUT BAGGAGE ROOM
Elevation 18.84'
LOCKER & WASH RM
TRAIN BOX & LOCKER RM
FAN RM
EXPRESS ROOM
Elevation 18.84
TRUCKING SPACE
Elevation 18.84'
CAB & AUTOMOBILE STAND
Elevation 15.9
UNASSIGNED
KITCHEN
LUNCH COUNTER
EMIGRANTS ROOM
Elevation 15.9'
MEN'S TOILET
WOMEN'S TOILET
382' 7 3/8"
13 of 28.6' = 381.6
80.0'

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Plate III

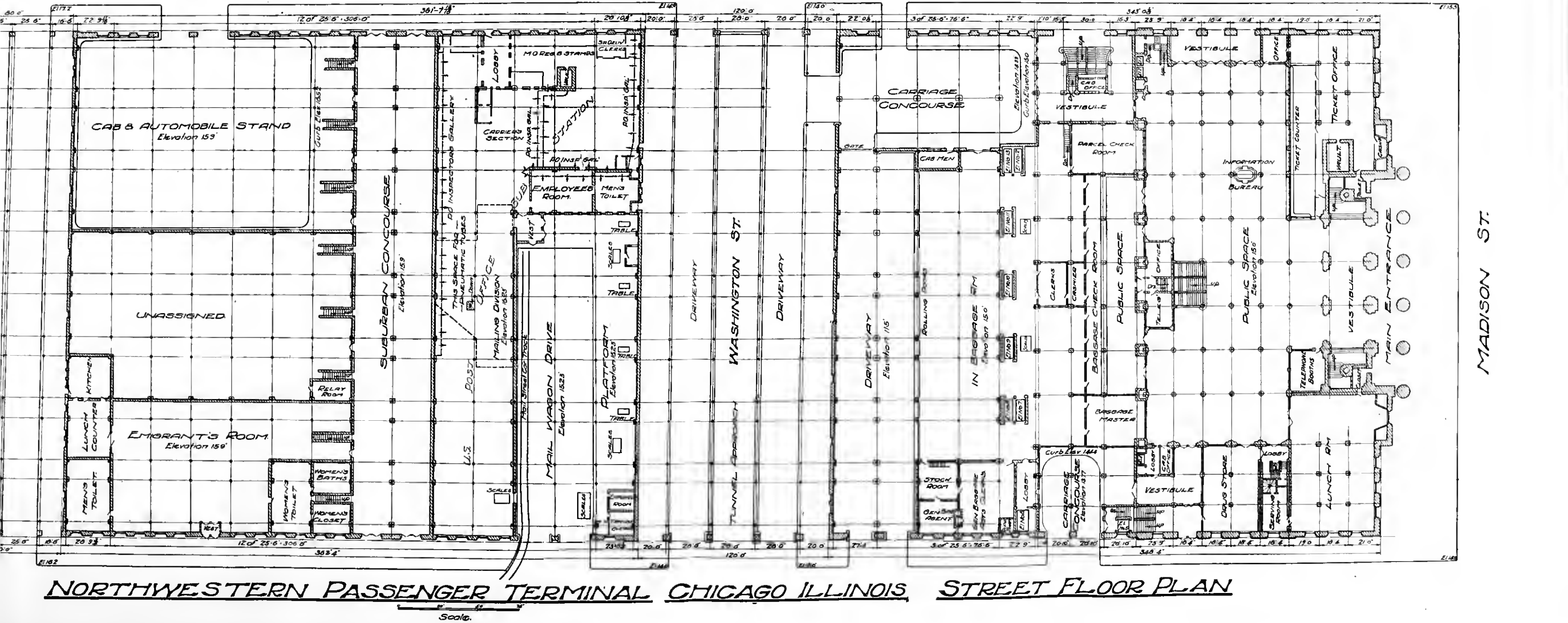
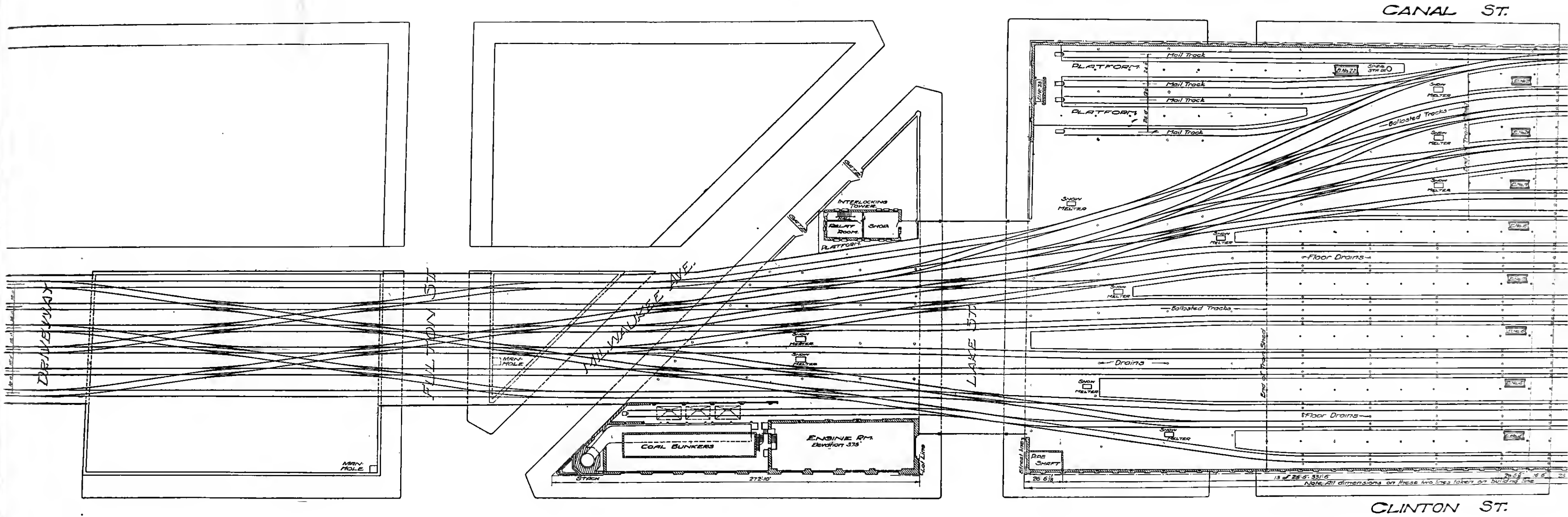
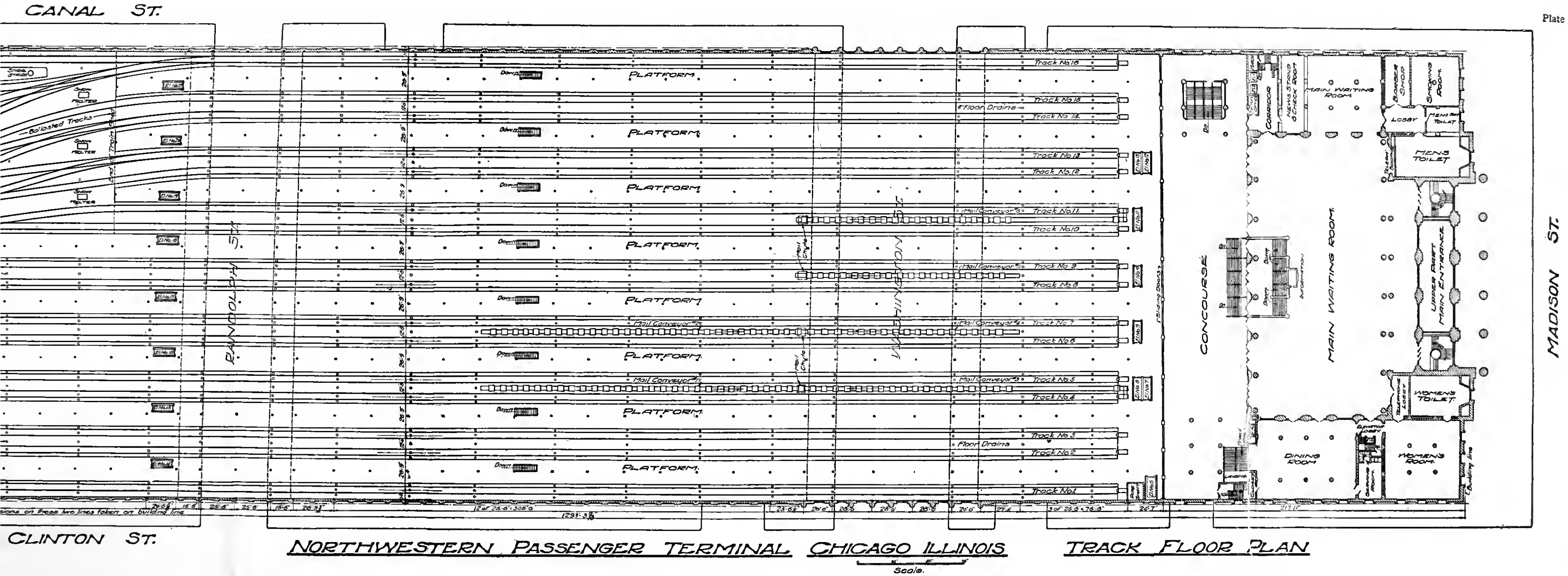


FIG. 8.



CANAL ST.
CLINTON ST.
DRIVEWAY
FULTON ST.
MILWAUKEE AVE.
LAKE ST.
MAN-HOLE
MAN-HOLE
GATE
GATE
INTERLOCKING TOWER.
RELAY ROOM.
SHOP
PLATFORM.
COAL BUNKERS
ENGINE RM.
Elevation 3.75'
STACK
272'-10"
Lot Line
Mail Track
PLATFORM.
Mail Track
Mail Track
PLATFORM.
Mail Track
B. No. 22
SIGNAL STORE
Snow Melter
Ballasted Tracks
Ballasted Tracks
Floor Drains
Floor Drains
Drains
End of Train Shed
Street line
PIPE SHAFT
26' 6 1/8"
13 of 25'-6"- 331'-6"
Note. All dimensions on these two lines taken on building line

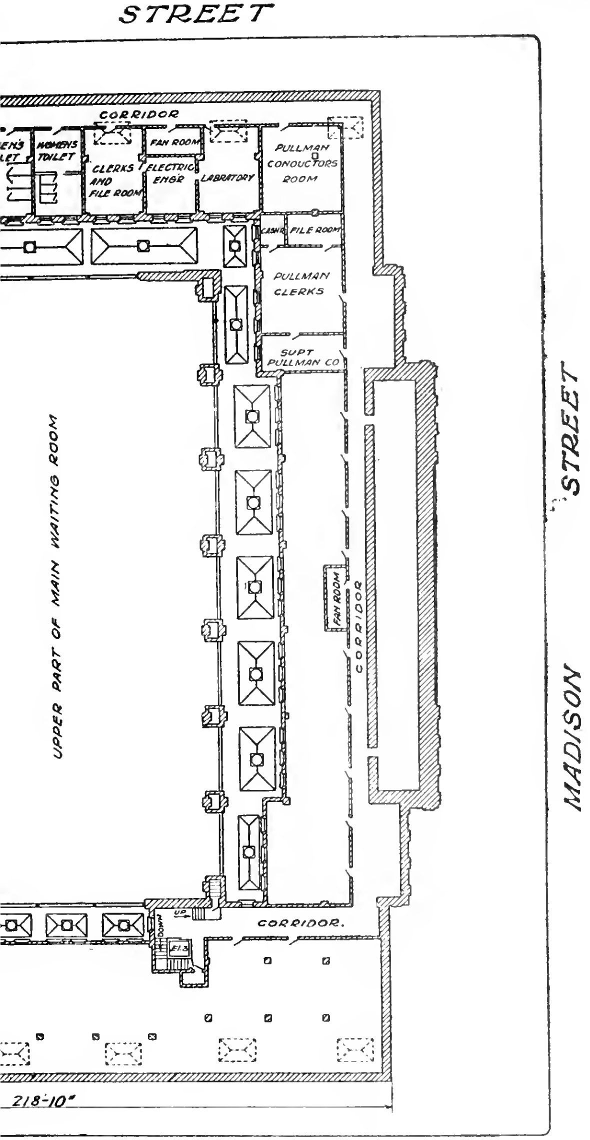
Plate IV



NORTHWESTERN PASSENGER TERMINAL CHICAGO ILLINOIS TRACK FLOOR PLAN

FIG. 9.

Plate V



FOURTH FLOOR PLAN

CHICAGO, ILLINOIS.

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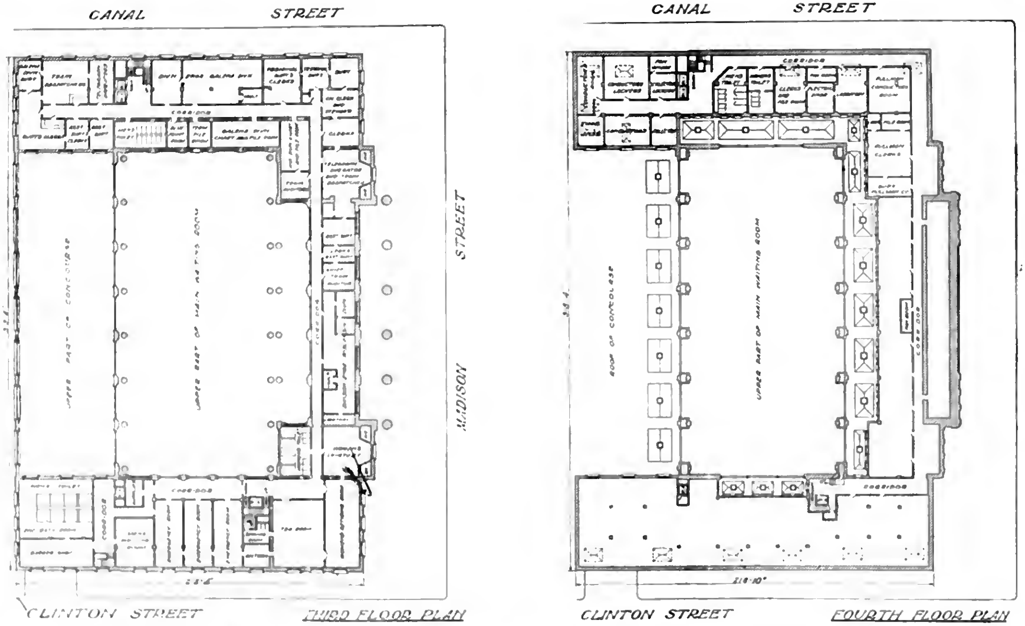
Plate V

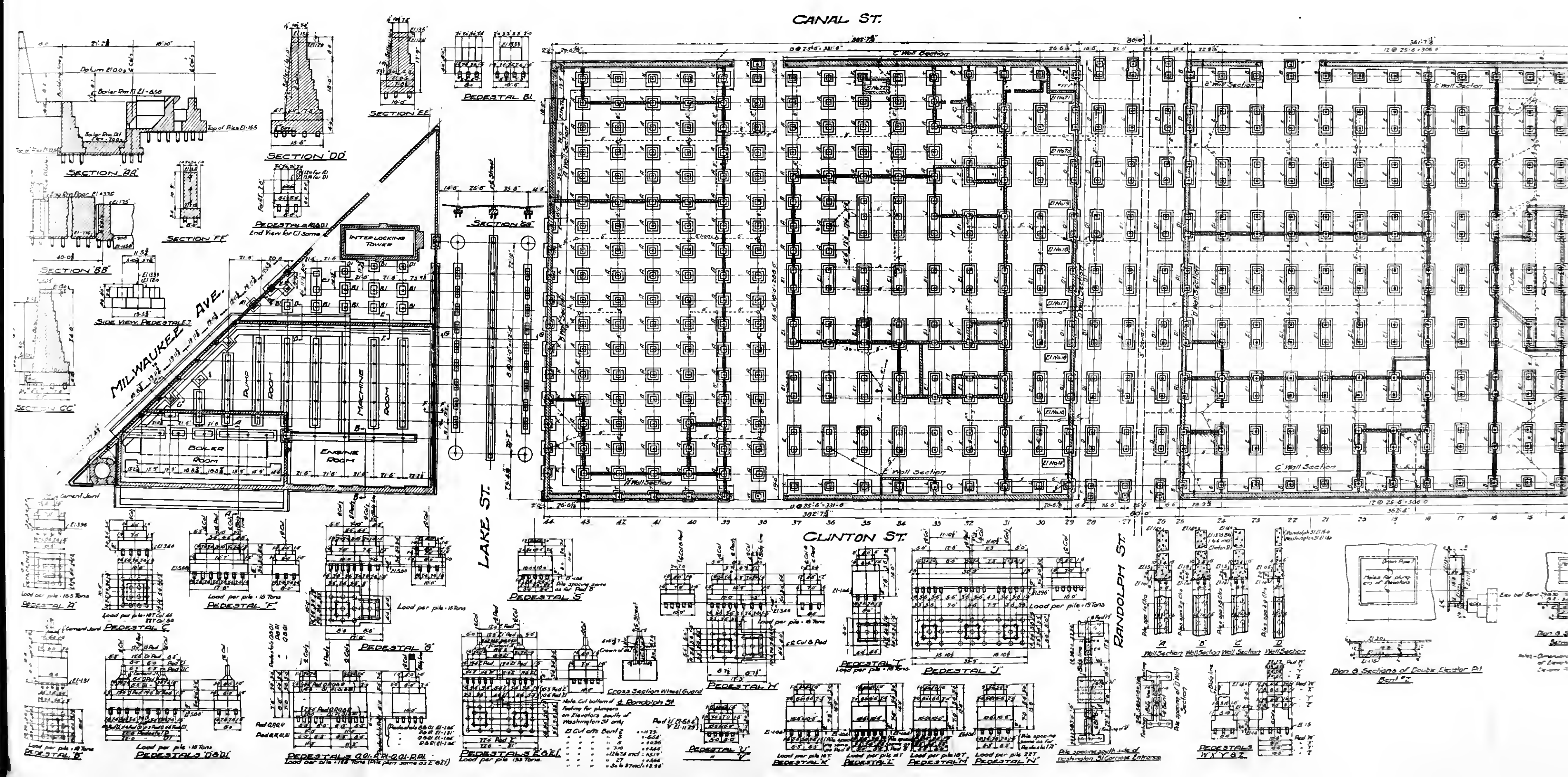


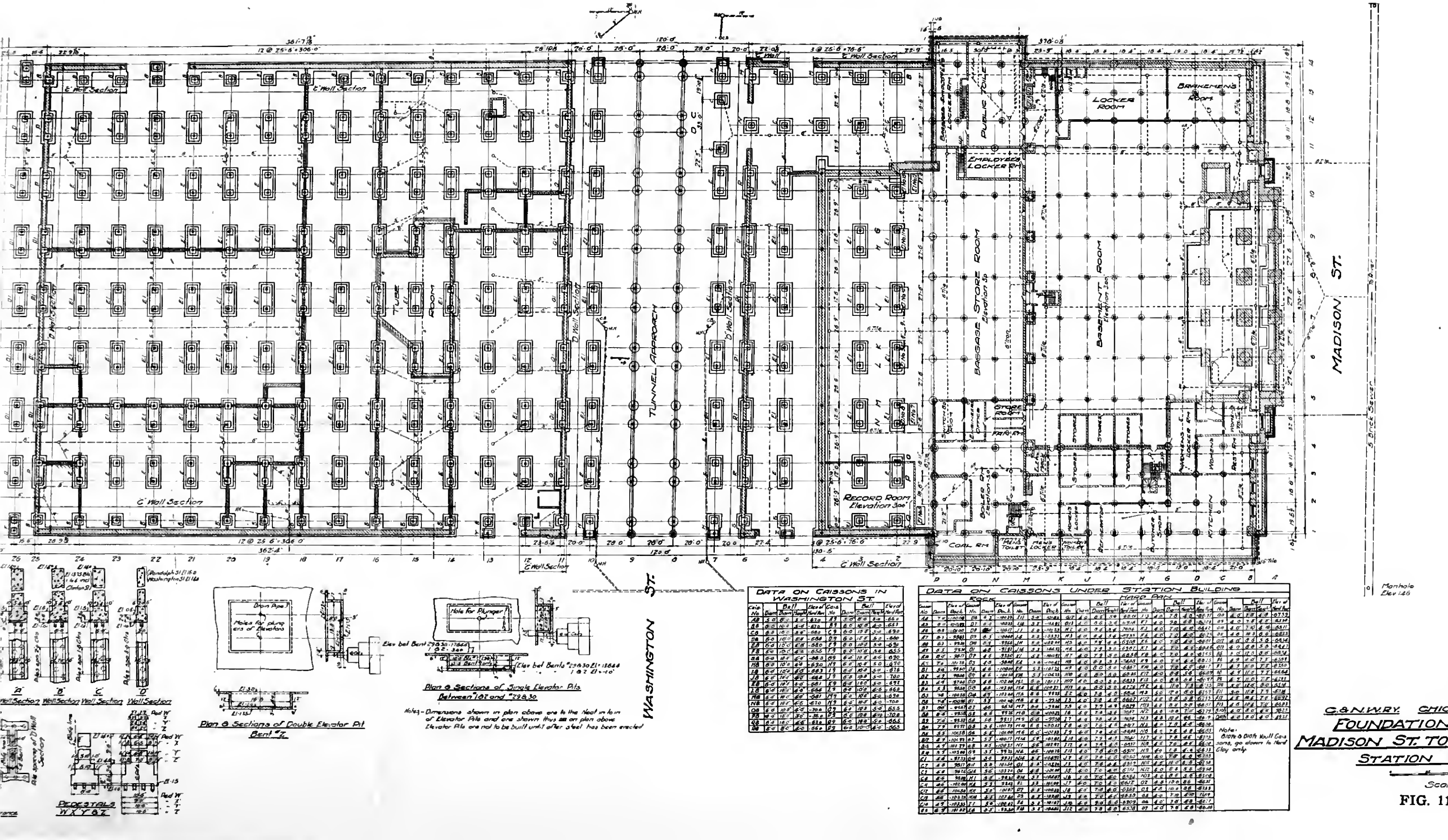
THIRD FLOOR PLAN

FOURTH FLOOR PLAN

NORTH WESTERN PASSENGER TERMINAL. CHICAGO, ILLINOIS.

FIG. 10.


CANAL ST.
CLINTON ST.
LAKE ST.
MILWAUKEE AVE.
RANDOLPH ST.
SECTION "AA"
SECTION "BB"
SECTION "CC"
SECTION "DD"
SECTION "EE"
SECTION "FF"
SECTION "GG"
PEDESTAL B1.
PEDESTALS A1 & D1
End View for C1 same
SIDE VIEW PEDESTAL E7
INTERLOCKING TOWER
PUMP ROOM
MACHINE ROOM
BOILER ROOM
ENGINE ROOM
C Wall Section
A Wall Section
E Wall Section
D Wall Section
Tube Room
PEDESTAL "A"
PEDESTAL "B"
PEDESTAL "C"
PEDESTAL "F"
PEDESTAL "G"
PEDESTAL "S"
PEDESTAL "H"
PEDESTAL "T"
PEDESTAL "J"
PEDESTAL "K"
PEDESTAL "L"
PEDESTAL "M"
PEDESTAL "N"
PEDESTAL "U" "V"
PEDESTALS "D" & "D1"
PEDESTALS Q.Q1-P.P1-Q.Q1-P.P1
PEDESTALS "E" & "E1"
PEDESTALS W X Y & Z
Load per pile - 16.5 Tons
Load per pile - 15 Tons
Load per pile - 16 Tons
Load per pile - 18 Tons
Load per pile - 19 Tons
Cross Section Wheel Guard
Pile spacing south side of Washington St Carriage Entrance
"A" Wall Section
"B" Wall Section
"C" Wall Section
"D" Wall Section
Plan & Sections of Double Elevator Pit
Bent #Z
Holes for plungers of Elevators
44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15


C' Wall Section
D' Wall Section
Tube Room
Tunnel Approach
Washington St.
Madison St.
Baggage Store Room Elevation 3.0
Basement Room Elevation 3.00
Record Room Elevation 3.00
Employees Locker Rm
Public Toilet
Locker Room
Brakemens Room
Coal Rm
Boiler Rm
Kitchen
Mens Toilet
Mens Locker
Womens Toilet
Womens Locker
Rest Rm
Store Room
Stores
5' Brick Sewer
Manhole Elev 14.6
'A' Wall Section
'B' Wall Section
'C' Wall Section
'D' Wall Section
Pedestals W X Y & Z
Plan & Sections of Double Elevator Pit Bent #2
Plan & Sections of Single Elevator Pits Between #18 and #29 & 30
Notes—Dimensions shown in plan above are to the Neat line of Elevator Pits and ones shown thus on plan above Elevator Pits are not to be built until after steel has been erected
Data on Caissons in Washington St.
Data on Caissons under Station Building
Note: Diam of ... Caissons go down to Hard Clay only

C.&N.W.RY. CHICAGO TERMINAL
FOUNDATION PLAN
MADISON ST. TO MILWAUKEE AVE.
STATION BUILDING
Scale

FIG. 11.

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Plate VII

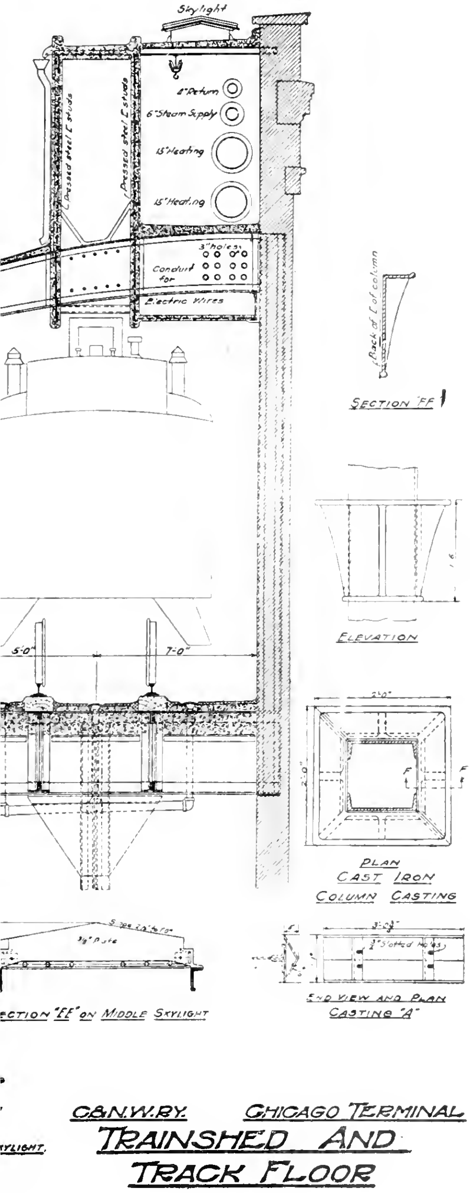


FIG. 13.

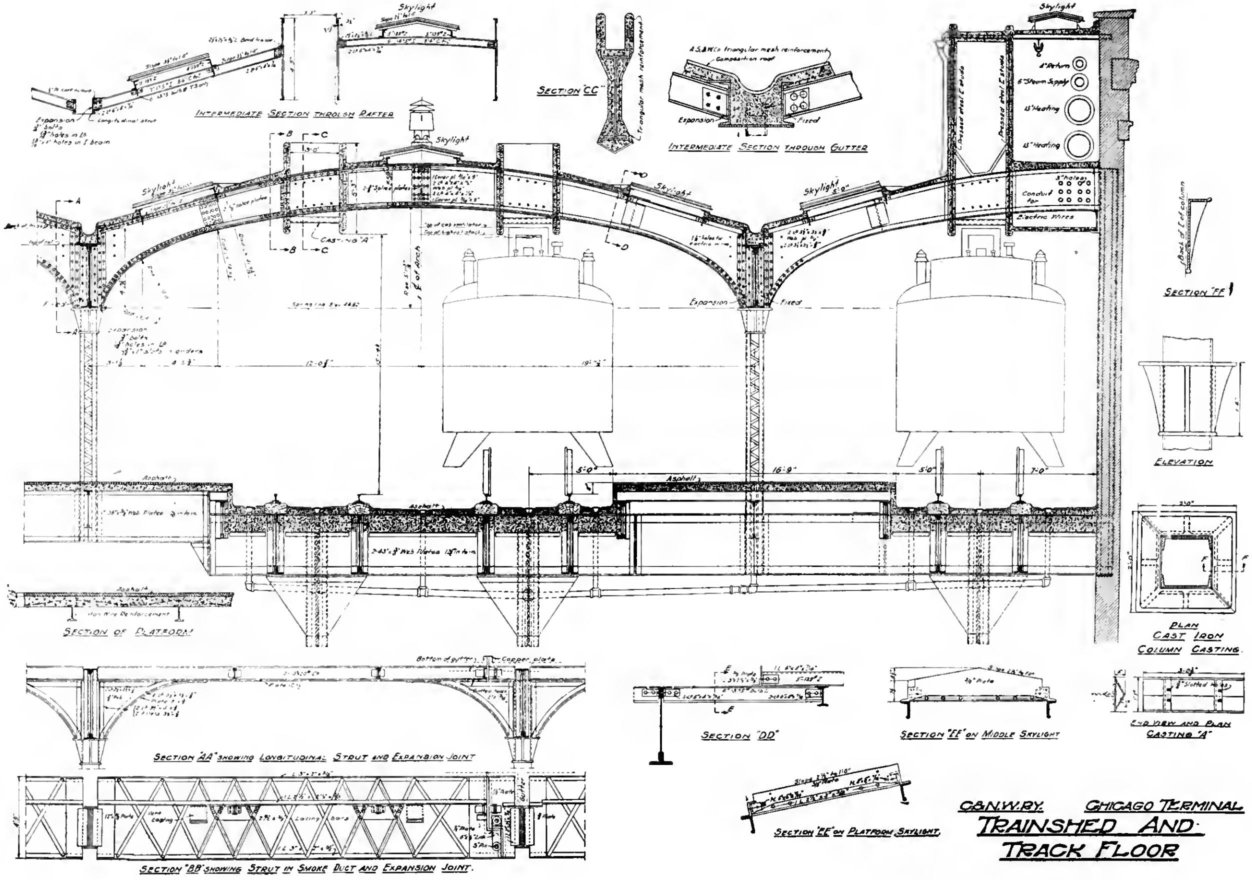
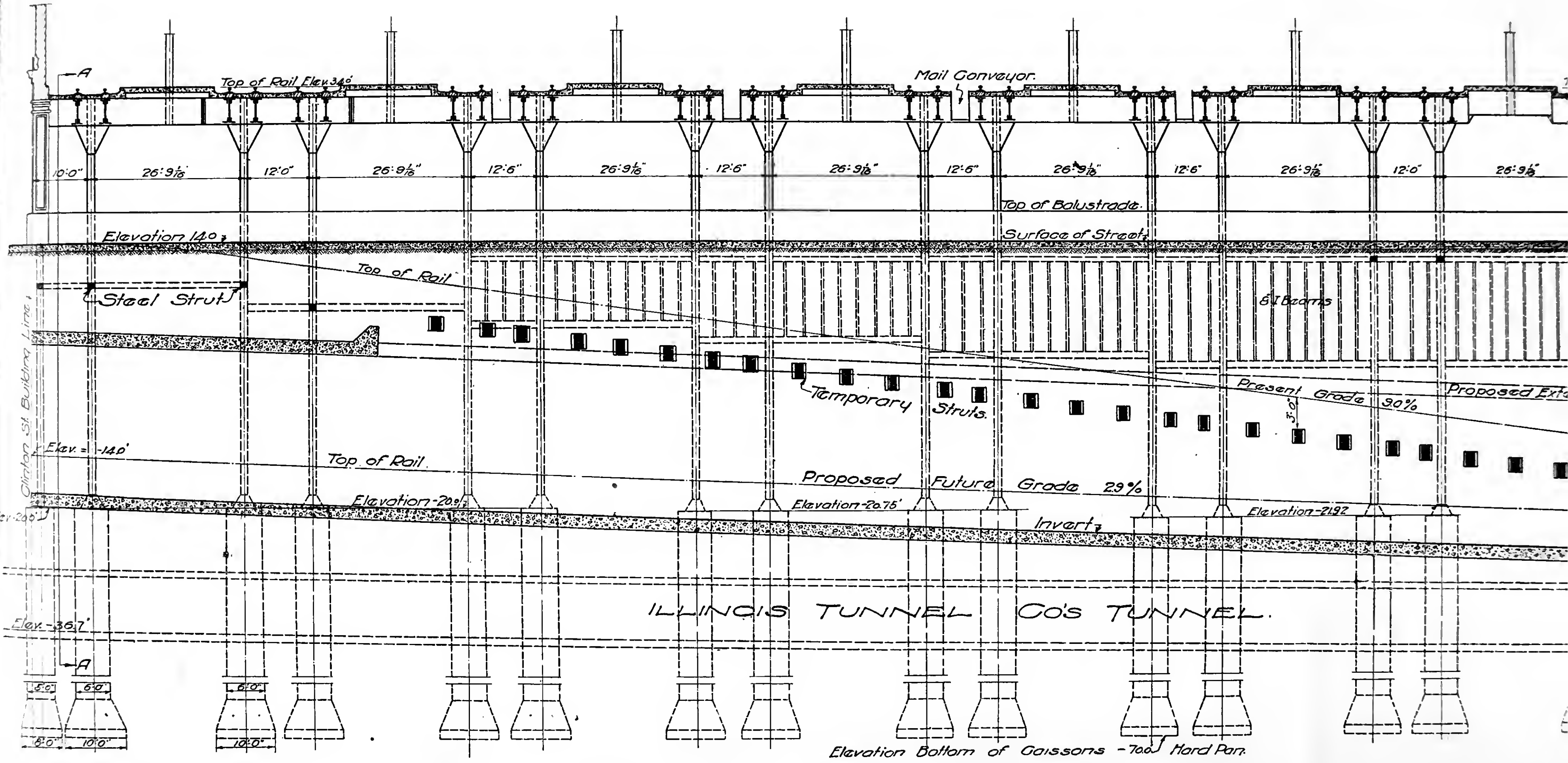

Intermediate Section through Rafter
Skylight
Section "CC"
Triangular mesh reinforcement
A.S.&W.Co. triangular mesh reinforcement
Composition roof
Expansion
Fixed
Intermediate Section through Gutter
4" Return
6" Steam Supply
15" Heating
15" Heating
Pressed steel E duct
Conduit for Electric Wires
Casting "A"
Spring line
Expansion
Fixed
Asphalt
Section "FF"
Elevation
Plan Cast Iron Column Casting
Section of Platform
Section "AA" showing Longitudinal Strut and Expansion Joint
Section "BB" showing Strut in Smoke Duct and Expansion Joint
Section "DD"
Section "EE" on Middle Skylight
End View and Plan Casting "A"
Section "EE" on Platform Skylight
C.&N.W.RY. CHICAGO TERMINAL
TRAINSHED AND TRACK FLOOR

FIG. 13.


A
Top of Rail Elev. 34.0'
Mail Conveyor.
10'-0"
26'-9 1/16"
12'-0"
26'-9 1/16"
12'-6"
26'-9 1/16"
12'-6"
26'-9 1/16"
12'-6"
26'-9 1/16"
12'-6"
26'-9 1/16"
12'-0"
26'-9 1/16"
Top of Balustrade.
Elevation 14.0
Surface of Street
Top of Rail
Steel Strut
8" I Beams
Clinton St. Building Line
Temporary Struts.
Present Grade 3.0%
Proposed Ext
3'-0"
Elev. = -14.0'
Top of Rail
Proposed Future Grade 2.9%
Elevation -20.0'
Elevation -20.75'
Elevation -21.92
Elev. -20.0'
Invert
ILLINOIS TUNNEL CO'S TUNNEL.
Elev. -36.7'
A
5'-0"
6'-0"
6'-0"
8'-0"
10'-0"
10'-0"
Elevation Bottom of Caissons -70.0' Hard Pan.
0 5 10'

SECTION "CC"

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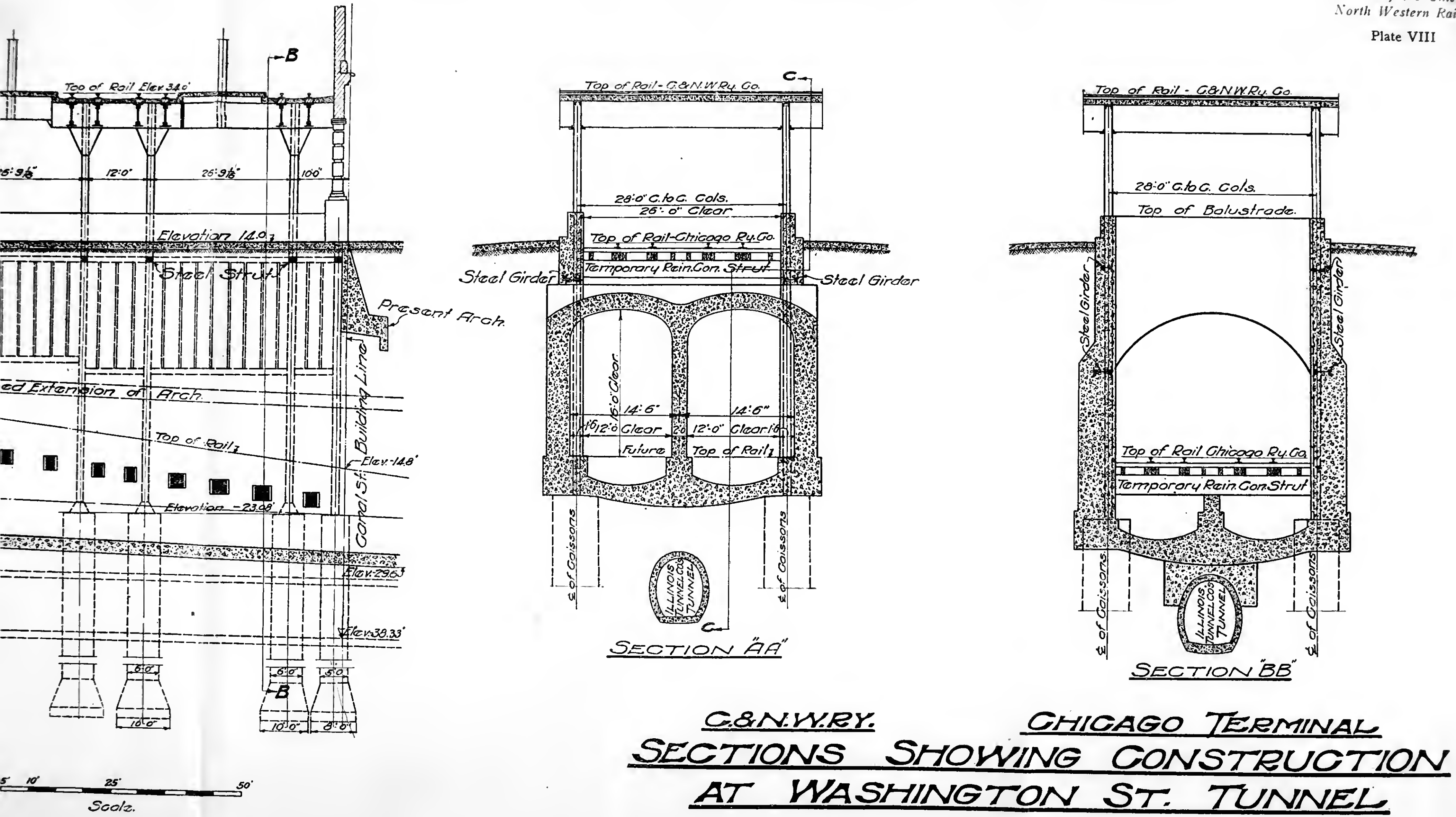
Plate VIII



C.&N.W.RY. CHICAGO TERMINAL
SECTIONS SHOWING CONSTRUCTION
AT WASHINGTON ST. TUNNEL

FIG. 18.

WESTERN SOCIETY OF ENGINEERS.
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Plate IX

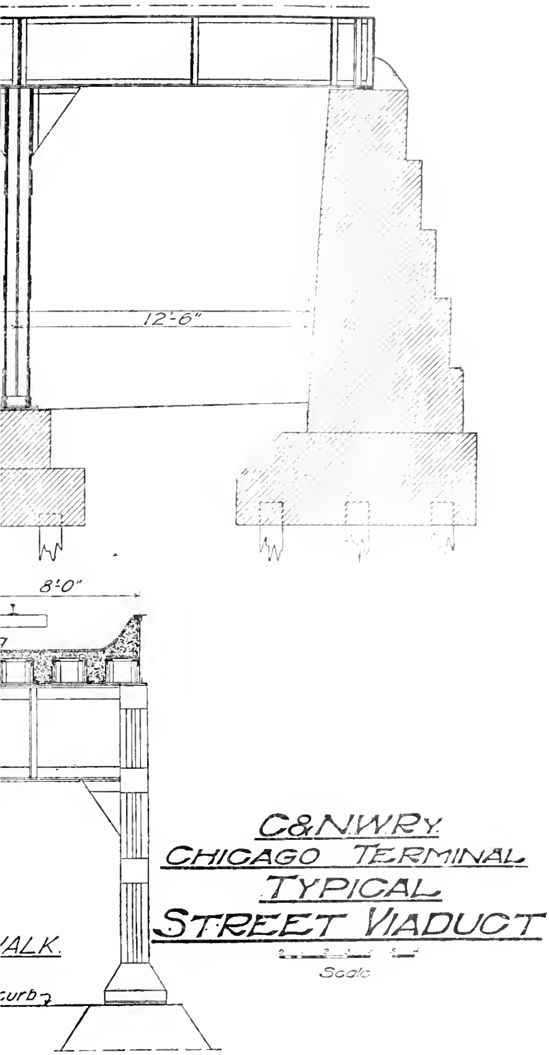

FIG. 25.

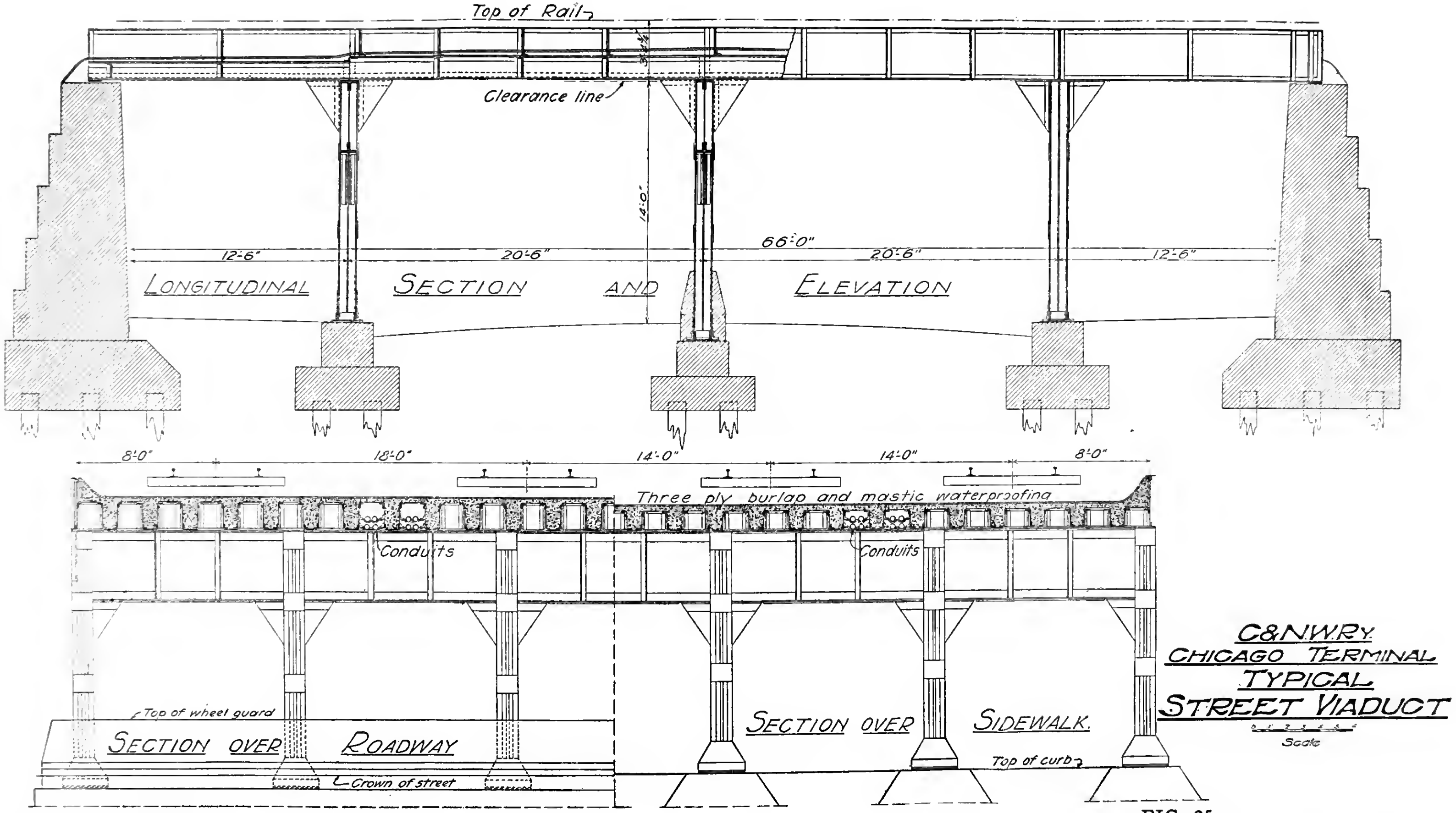
Top of Rail
Clearance line
14'-0"
66'-0"
12'-6"
20'-6"
20'-6"
12'-6"
LONGITUDINAL SECTION AND ELEVATION
8'-0"
18'-0"
14'-0"
14'-0"
8'-0"
Three ply burlap and mastic waterproofing
Conduits
Conduits
Top of wheel guard
SECTION OVER ROADWAY
Crown of street
SECTION OVER SIDEWALK.
Top of curb
C&N.W.Ry.
CHICAGO TERMINAL
TYPICAL
STREET VIADUCT
Scale

FIG. 25.

Plate X

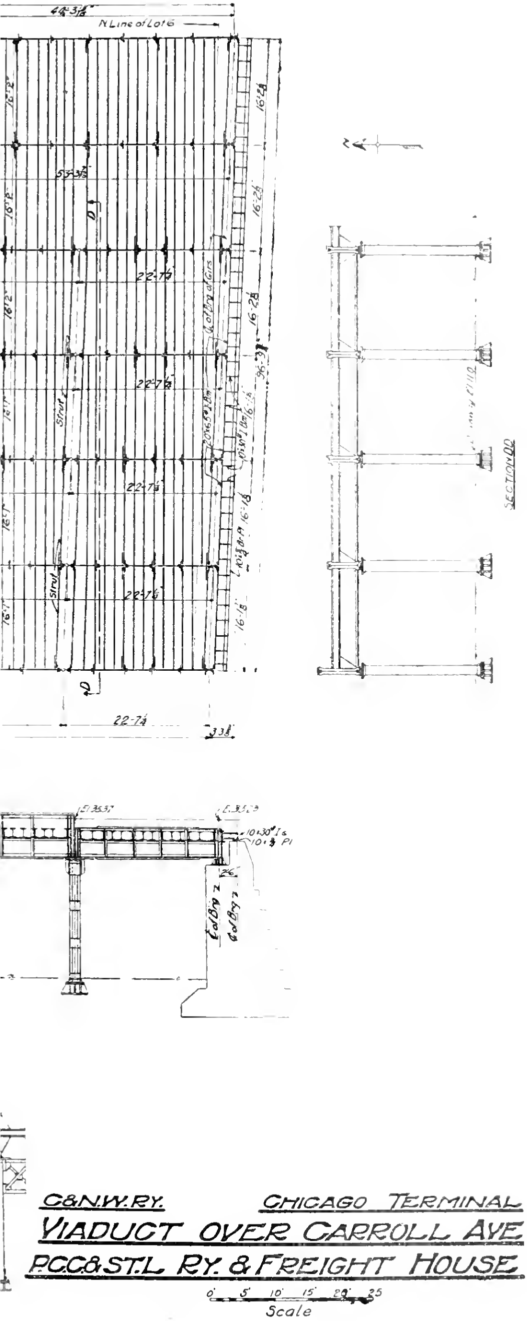

FIG. 27.

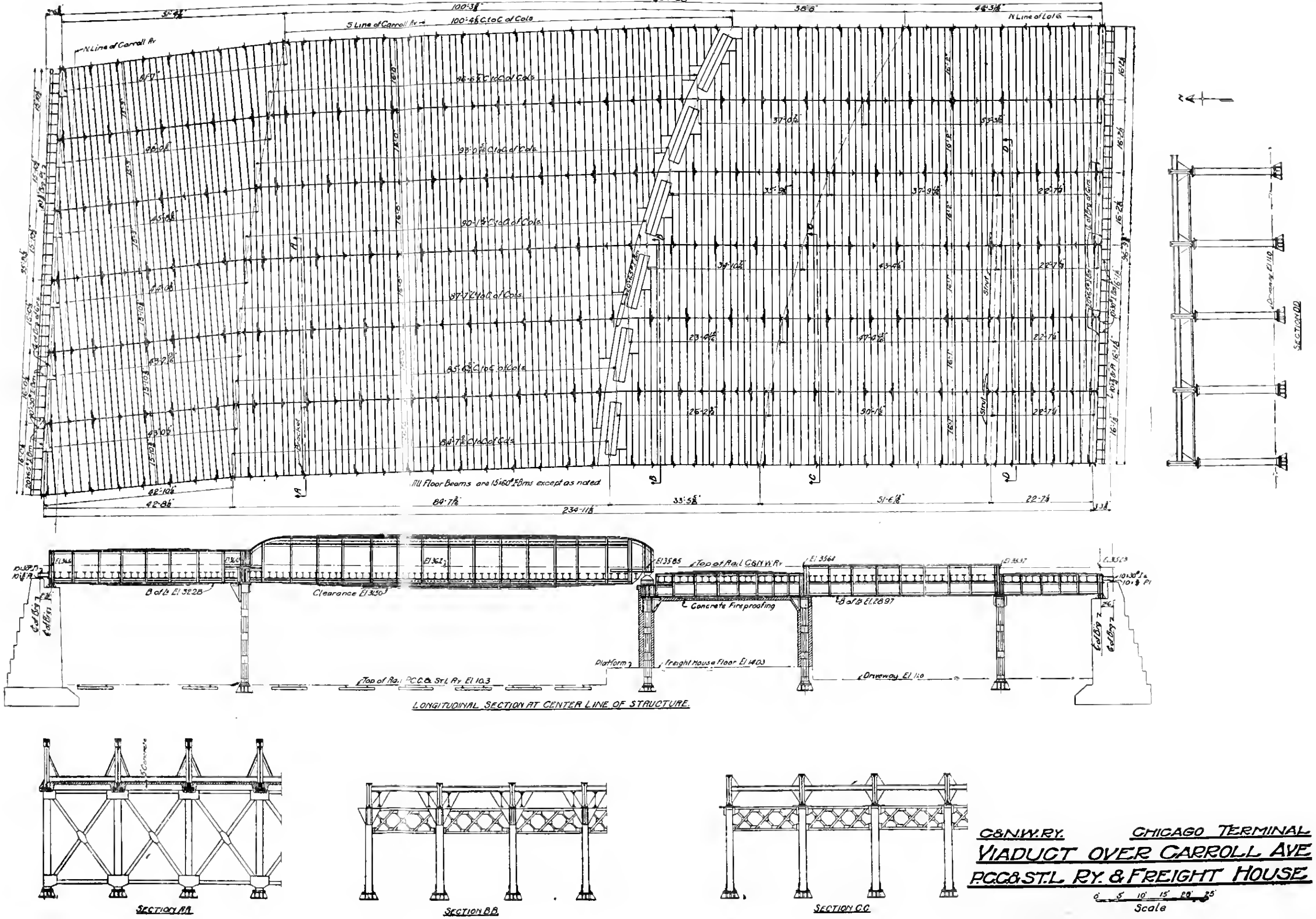
234-8⅝"
100-3⅞"
38-6"
44-3⅛"
S Line of Carroll Av.
100-4⅝ C to C of Cols
N Line of Lot 6
N Line of Carroll Av
96-6⅞ C to C of Cols
93-0½ C to C of Cols
90-1⅛ C to C of Cols
87-7¼ C to C of Cols
85-6⅞ C to C of Cols
83-7⅞ C to C of Cols
All Floor Beams are 15" 60# I Bms except as noted
42-10⅛
42-8⅝
89-7⅞
33-5⅝
51-6⅝
22-7⅛
234-11⅛
Section DD
Longitudinal Section at Center Line of Structure.
B of R El 32.28
Clearance El 31.50
Top of Rail C&N.W. Ry.
Concrete Fireproofing
B of R El 28.97
Platform
Freight House Floor El 14.03
Driveway El 11.0
Top of Rail P.C.C.& St.L. Ry. El 10.3
Section AA
Section BB
Section CC
C&N.W.RY.
CHICAGO TERMINAL
VIADUCT OVER CARROLL AVE
P.C.C.&ST.L. RY. & FREIGHT HOUSE
0 5 10 15 20 25
Scale

FIG. 27.

Plate XI

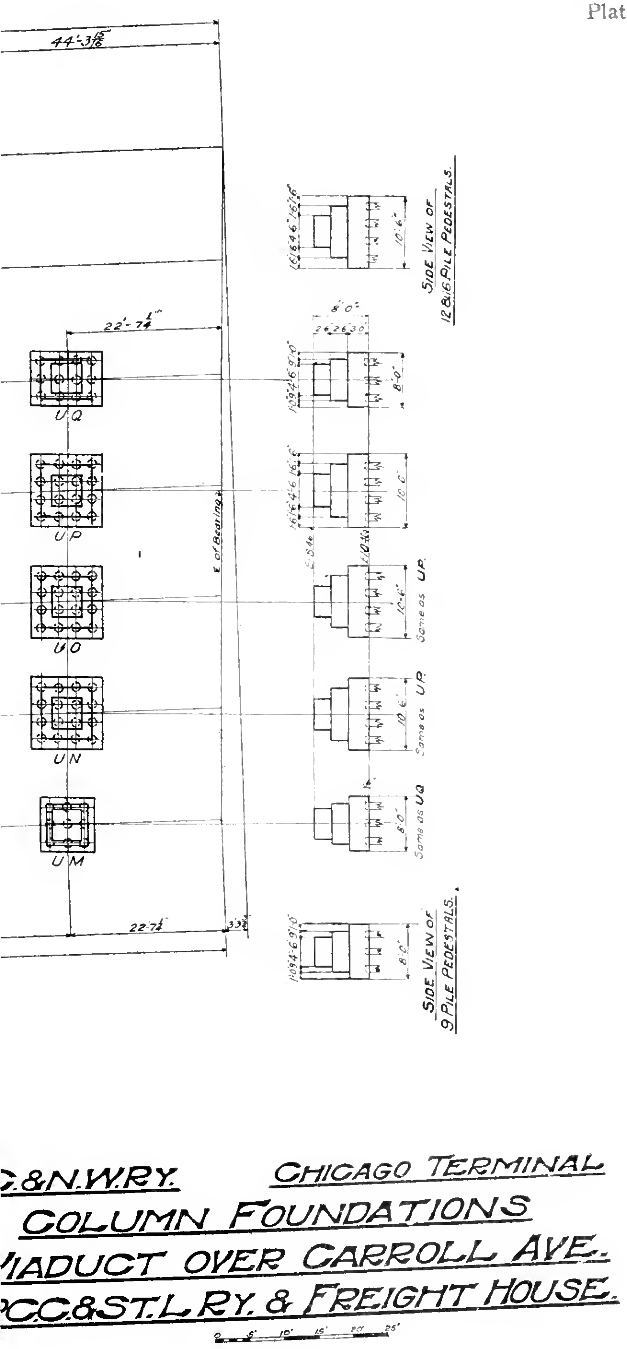

FIG. 28.

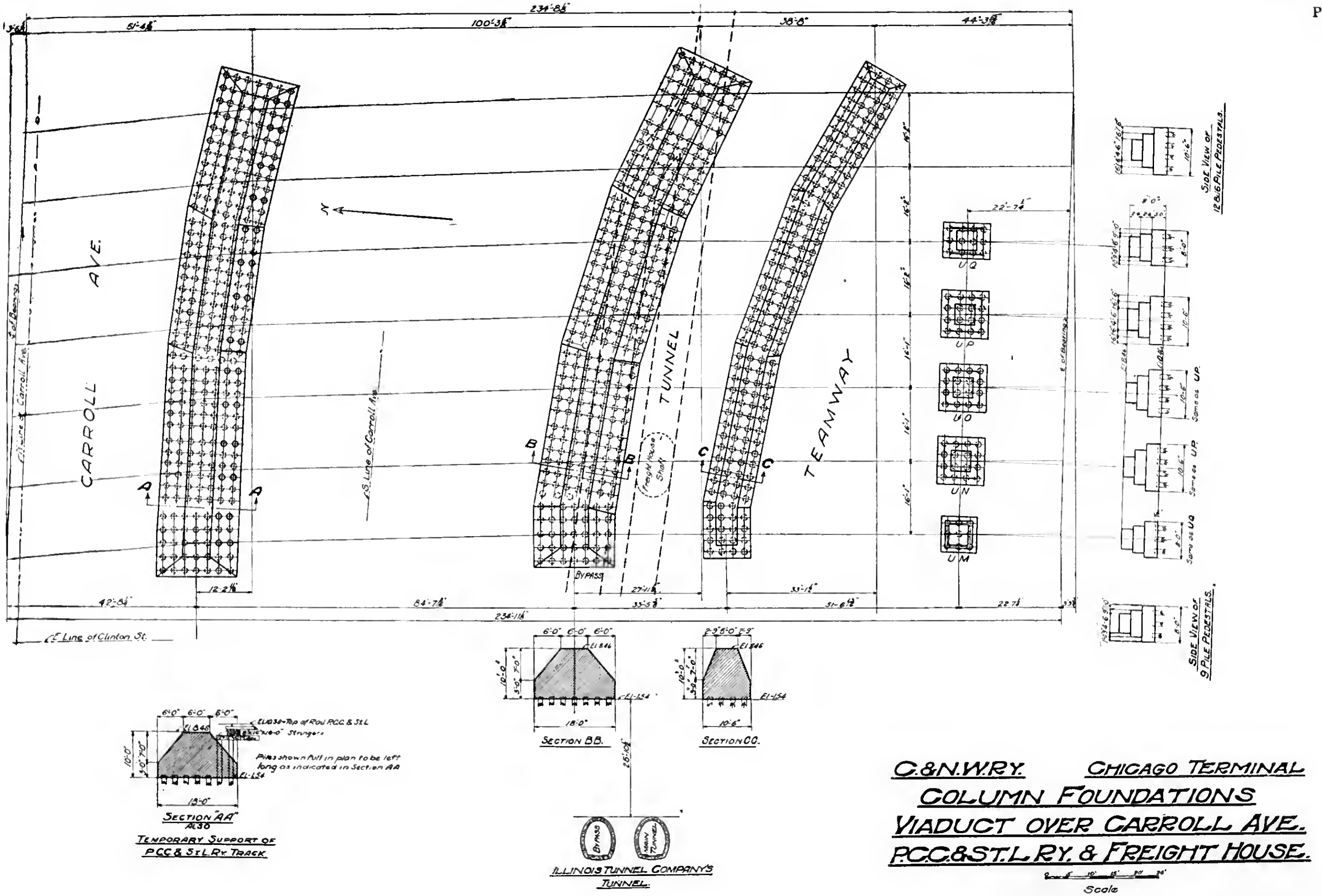
234'-8¾"
51'-4½"
100'-3⅝"
38'-8"
44'-3⅝"
CARROLL AVE.
TUNNEL
TEAMWAY
Freight House Shaft
BYPASS
A
A
B
B
C
C
N
UQ
UP
UO
UN
UM
22'-7¼"
16'-2"
16'-1"
42'-8¼"
84'-7⅝"
27'-1⅛"
33'-5⅜"
33'-1¼"
51'-6½"
22'-7¼"
234'-11⅛"
12'-2⅛"
E Line of Clinton St.
S Line of Carroll Ave.
Side View of 12 & 16 Pile Pedestals.
Side View of 9 Pile Pedestals.
Same as UP.
Same as UQ.
6'-0" 6'-0" 6'-0"
El 8.46
El -1.54
18'-0"
Section BB.
2'-9" 6'-0" 2'-9"
10'-6"
Section CC.
El 10.34 Top of Rail P.C.C. & St.L.
Piles shown full in plan to be left long as indicated in Section AA
13'-0"
Section "AA"
Temporary Support of P.C.C. & St.L. Ry. Track
26'-10"
Bypass
Main Tunnel
Illinois Tunnel Company's Tunnel.
C.&N.W.RY. CHICAGO TERMINAL
COLUMN FOUNDATIONS
VIADUCT OVER CARROLL AVE.
P.C.C.&ST.L.RY. & FREIGHT HOUSE.
Scale

FIG. 28.

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Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

Plate XII

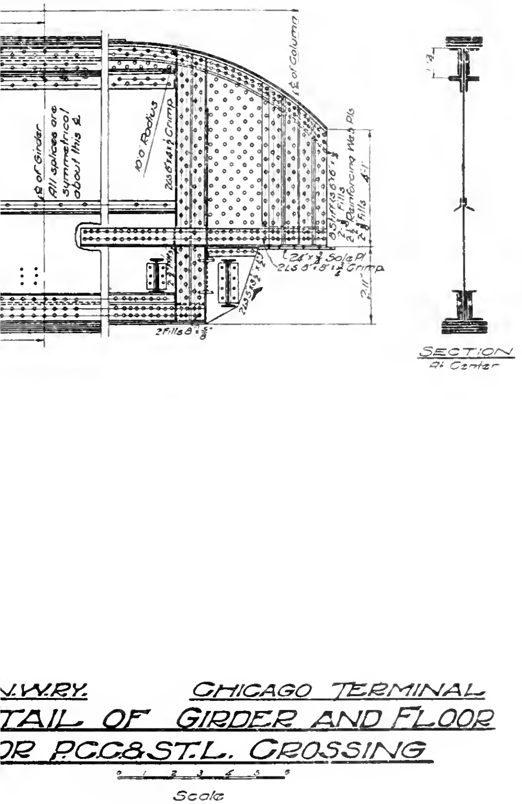
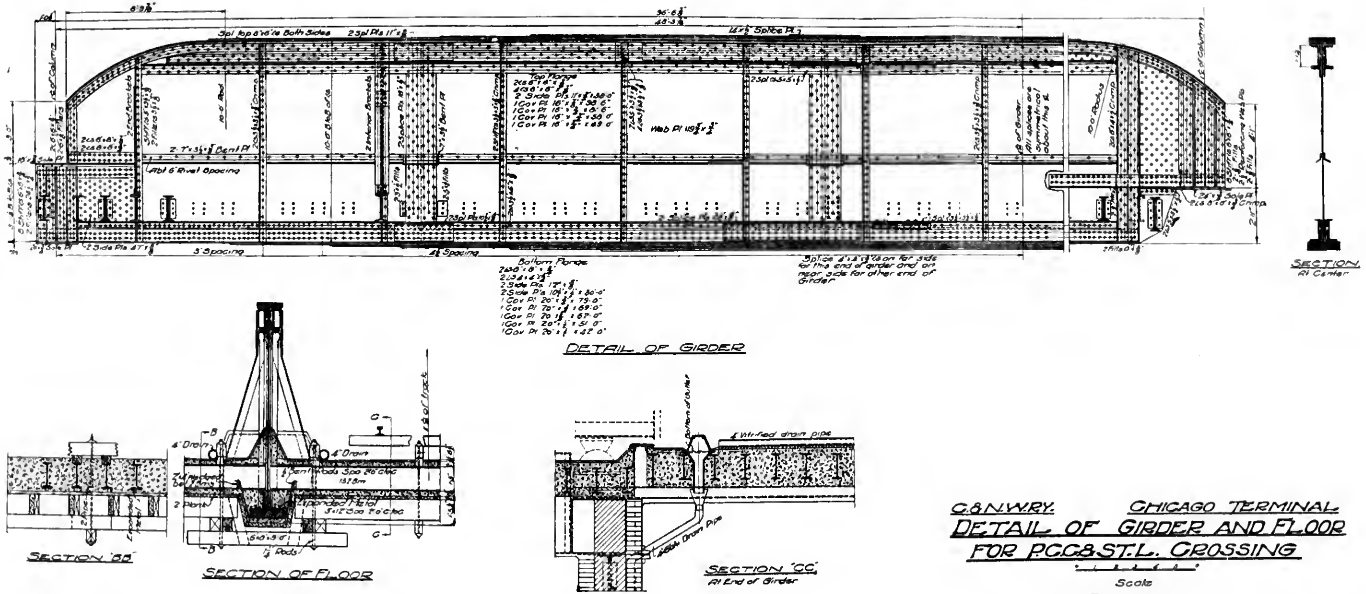


FIG. 29.

Plate XII



C.&N.W.RY. CHICAGO TERMINAL
DETAIL OF GIRDER AND FLOOR
FOR P.C.C.&ST.L. CROSSING

Scale

FIG. 29.

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Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

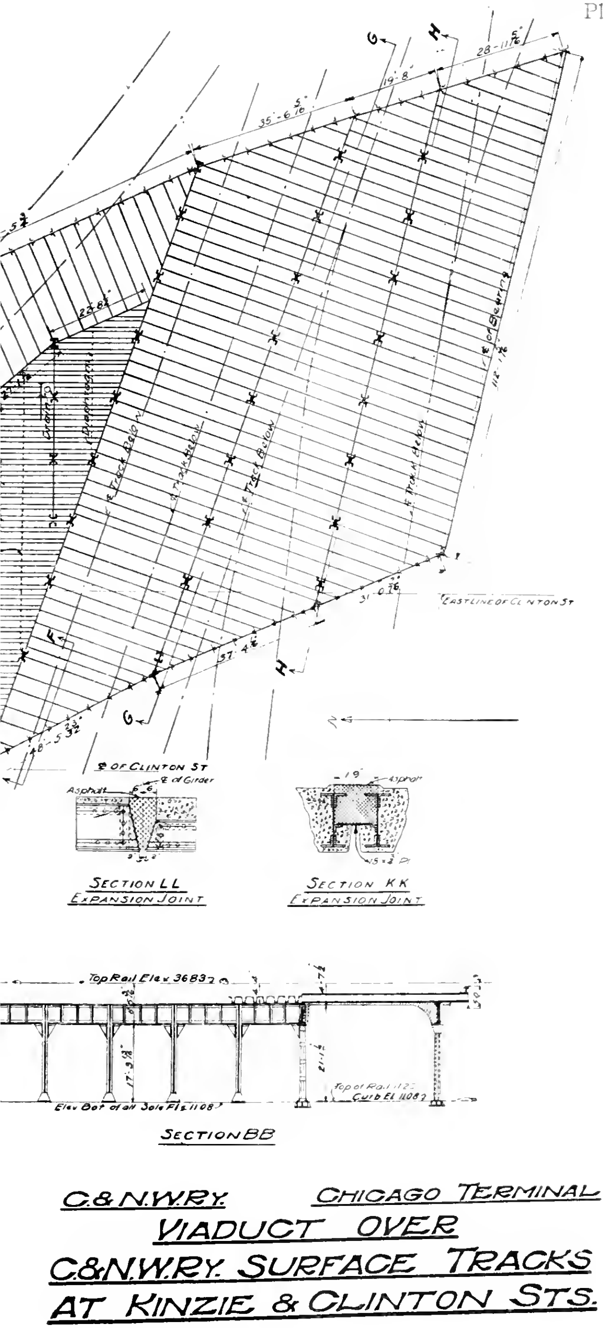

FIG. 30.

WESTERN SOCIETY OF ENGINEERS.
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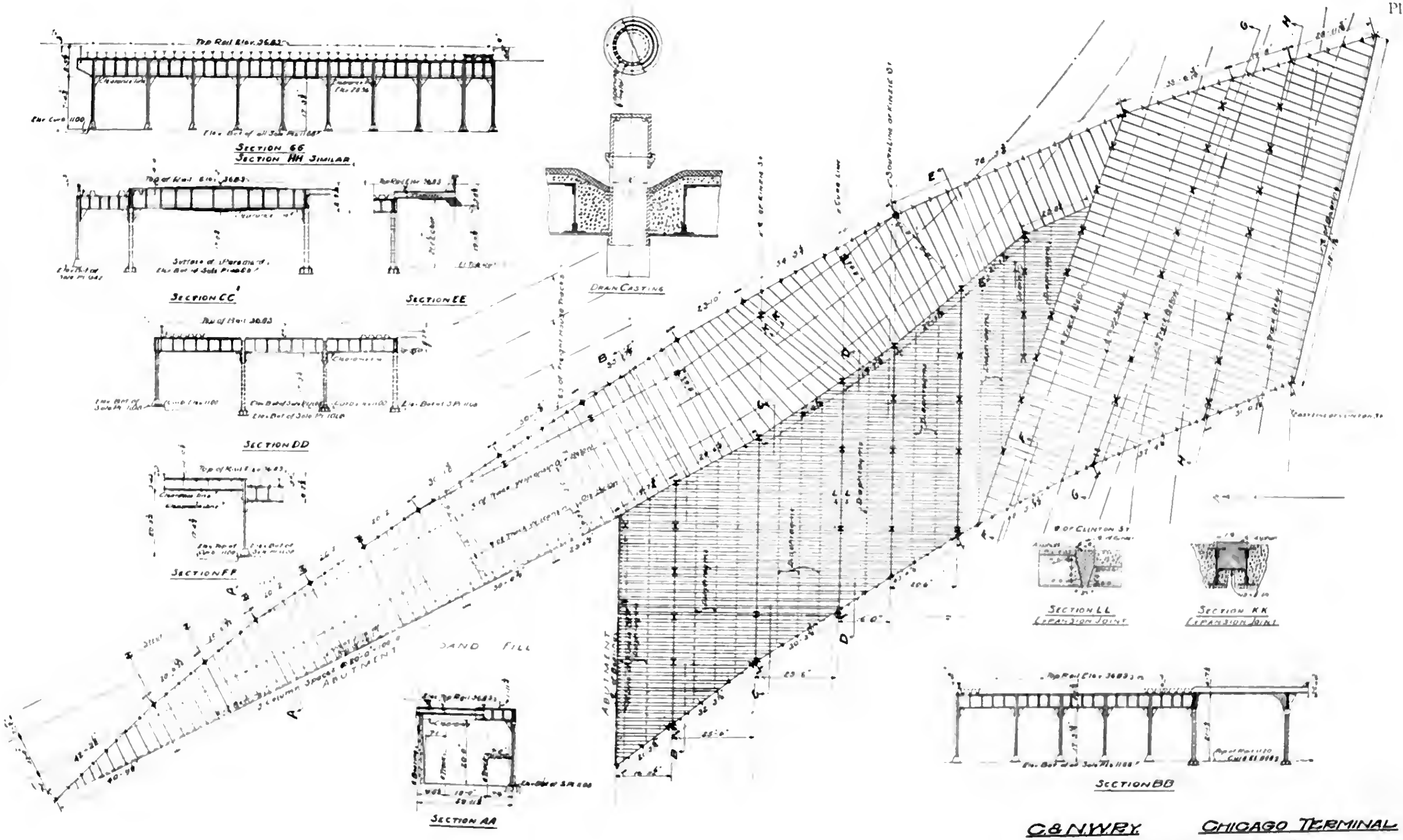
Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

Plate XIII



C.&N.W.RY. CHICAGO TERMINAL
VIADUCT OVER
C.&N.W.RY. SURFACE TRACKS
AT KINZIE & CLINTON STS.

FIG. 30.

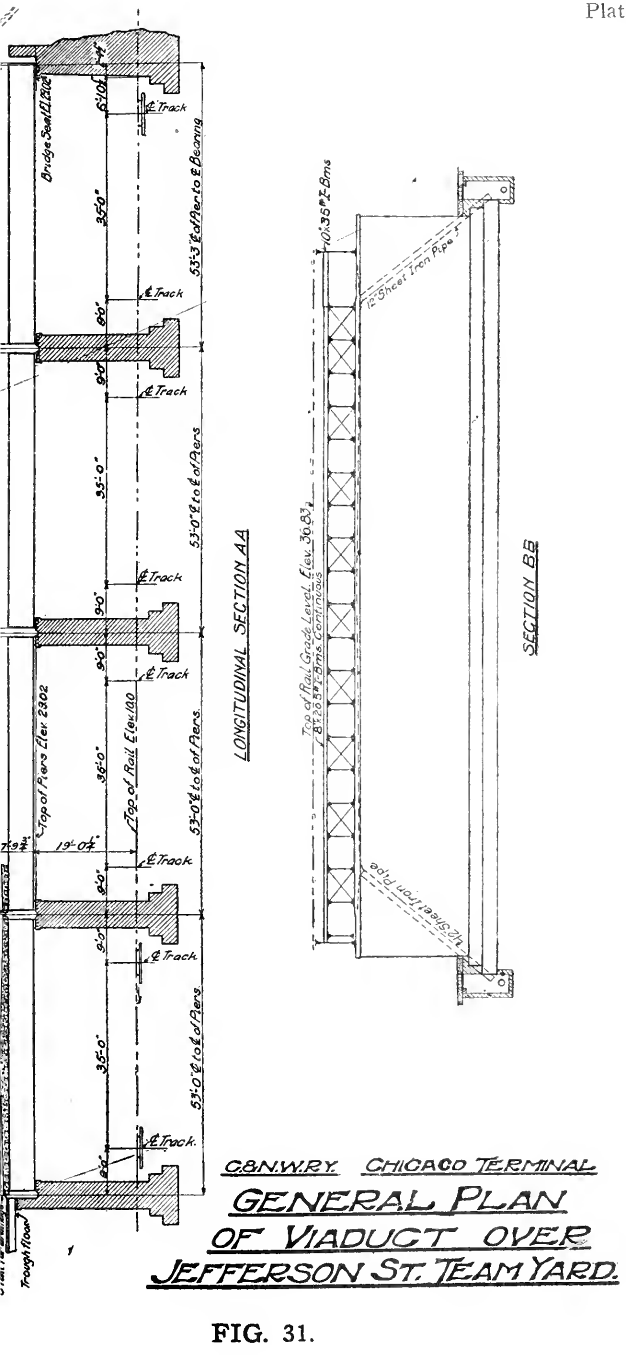

Bridge Seat El. 23.02
℄ Track
35'-0"
53'-3" ℄ of Pier to ℄ Bearing
9'-0"
35'-0"
53'-0" ℄ to ℄ of Piers
Top of Piers Elev. 23.02
Top of Rail Elev. 10.0
19'-0¼"
7'-9¾"
Trough Floor
LONGITUDINAL SECTION AA
10"x35# I-Bms
12" Sheet Iron Pipe
Top of Rail Grade Level. Elev. 36.83
8"x25.5# I-Bms. Continuous
SECTION BB
C.&N.W.RY. CHICAGO TERMINAL
GENERAL PLAN
OF VIADUCT OVER
JEFFERSON ST. TEAM YARD.

FIG. 31.

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Armstrong—The New Passenger Terminal of the Chicago and North Western Railway.

Plate XIV

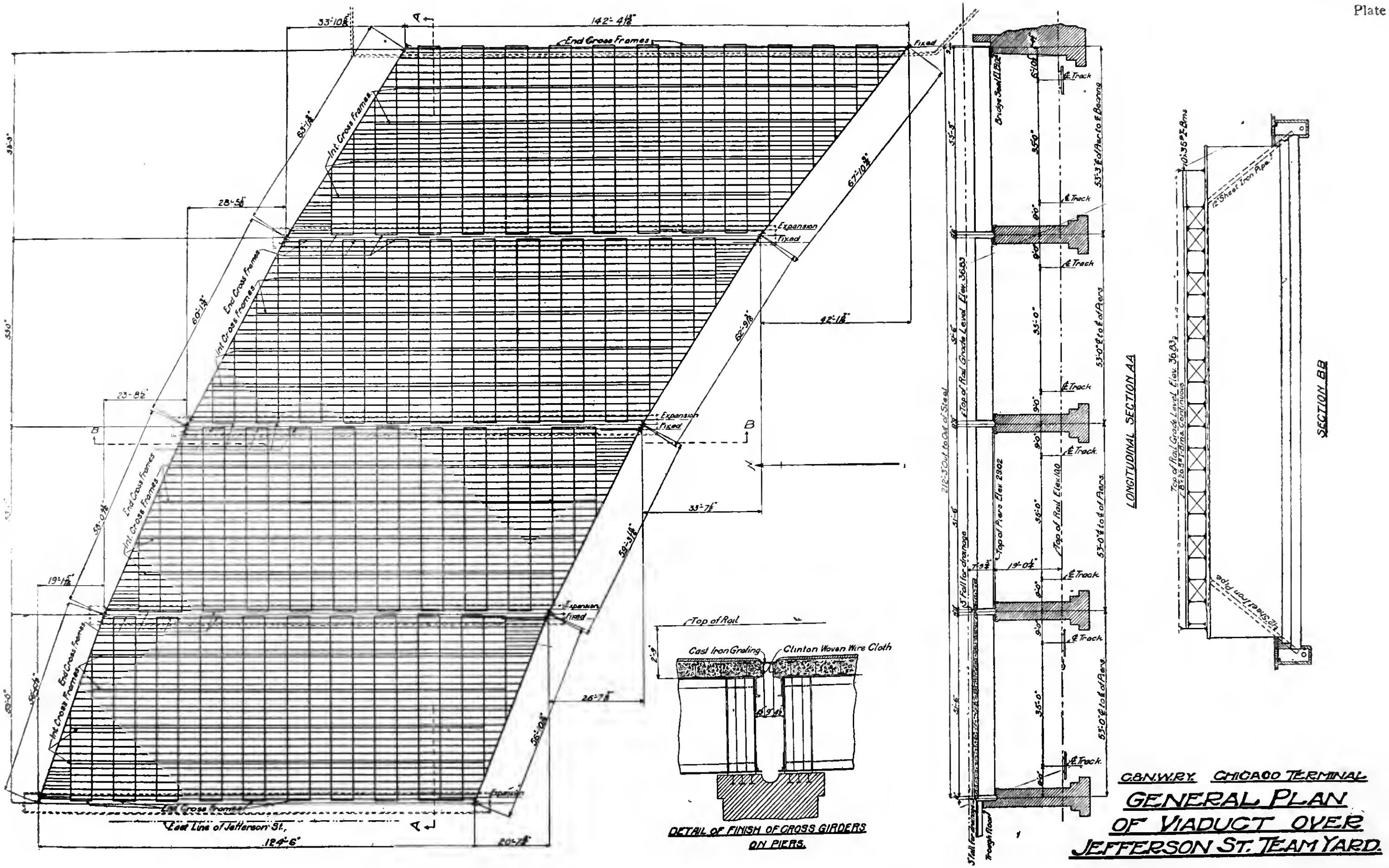

FIG. 31.

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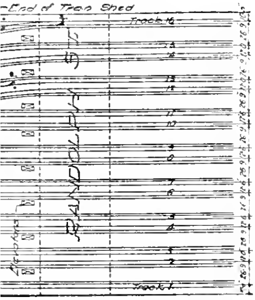
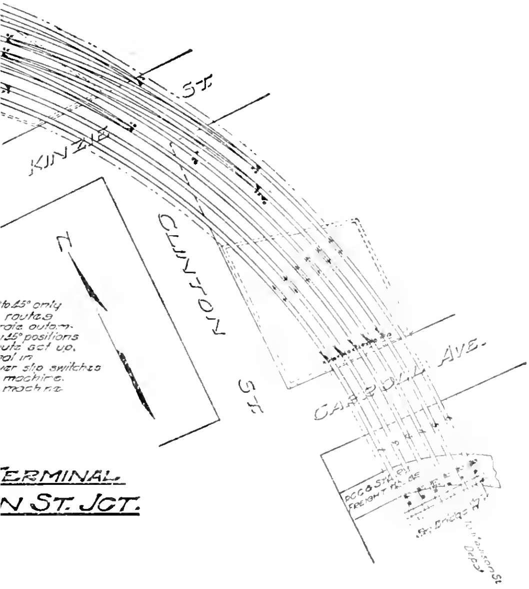
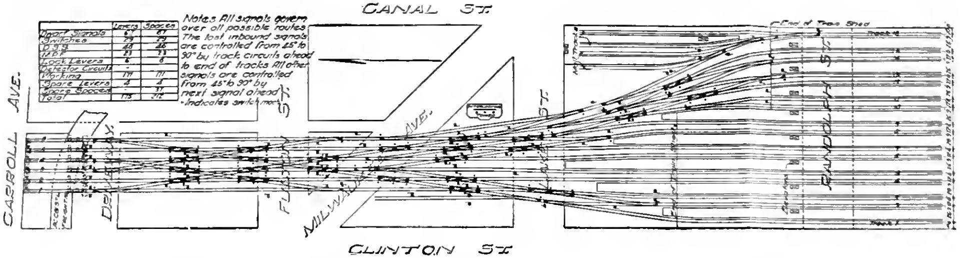
Peabody—Signaling and Interlocking.

Plate XV.



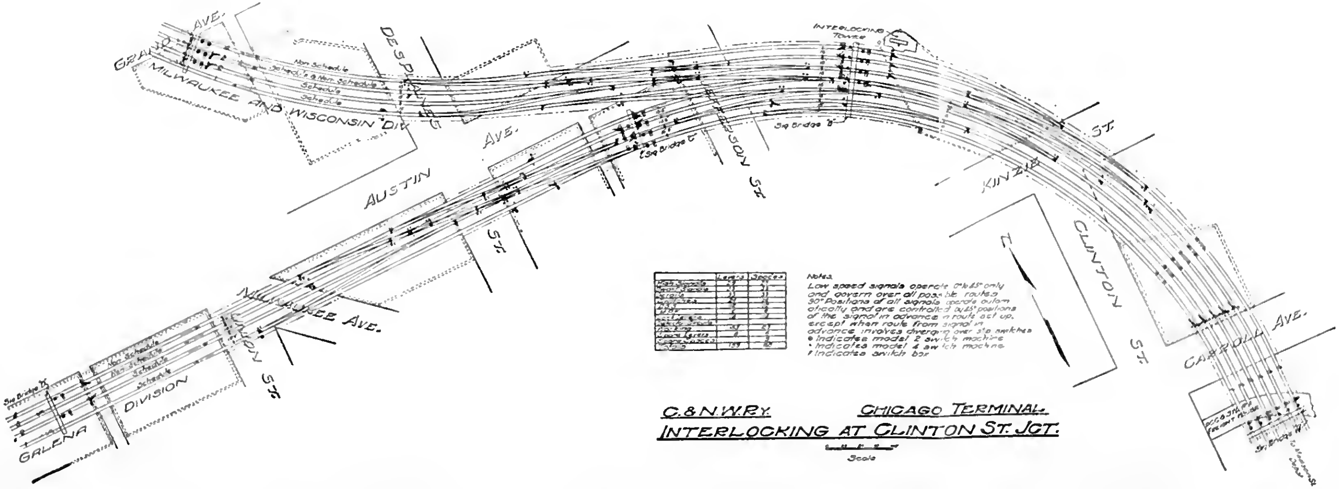




	Levers	Spaces
Dwarf Signals	67	67
Switches	29	29
D.S.S.	46	46
M.D.F.	23	23
Lock Levers	6	6
Detector Circuits	-	
Working	171	171
Spare Levers	4	4
Spare Spaces	-	37
Total	175	212

Notes: All signals govern over all possible routes. The last inbound signals are controlled from 45° to 90° by track circuits ahead to end of tracks. All other signals are controlled from 45° to 90° by next signal ahead.
• Indicates switch mot.

Lake Street Interlocking. Plate XV—A.



Notes.
Low speed signals operate 0° to 45° only and govern over all possible routes. 90° Positions of all signals operate automatically and are controlled by 45° positions of the signal in advance in route set up, except when route from signal in advance involves diverging over slip switches.
● Indicates model 2 switch machine
• Indicates model 4 switch machine
! Indicates switch box

Clinton Street Interlocking. Plate XV—B.

Western Society of Engineers.
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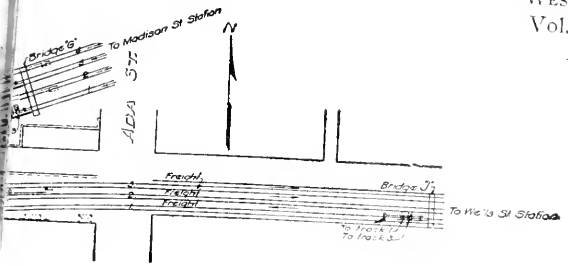
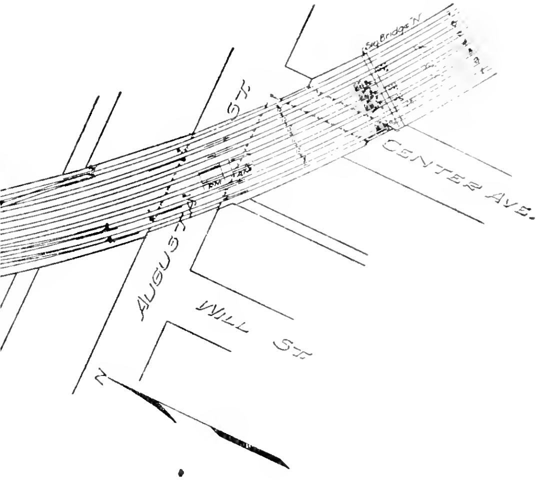
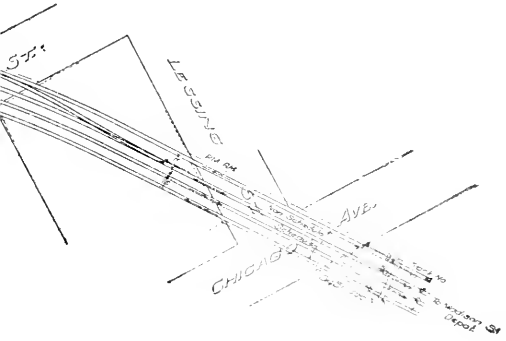
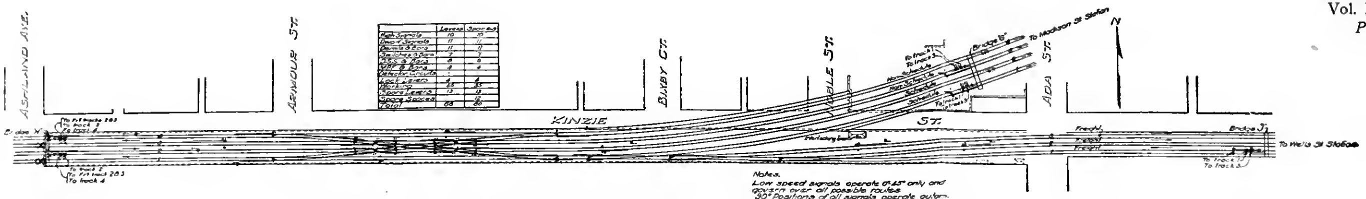
Peabody—Signaling and Interlocking.

Plate XVI.





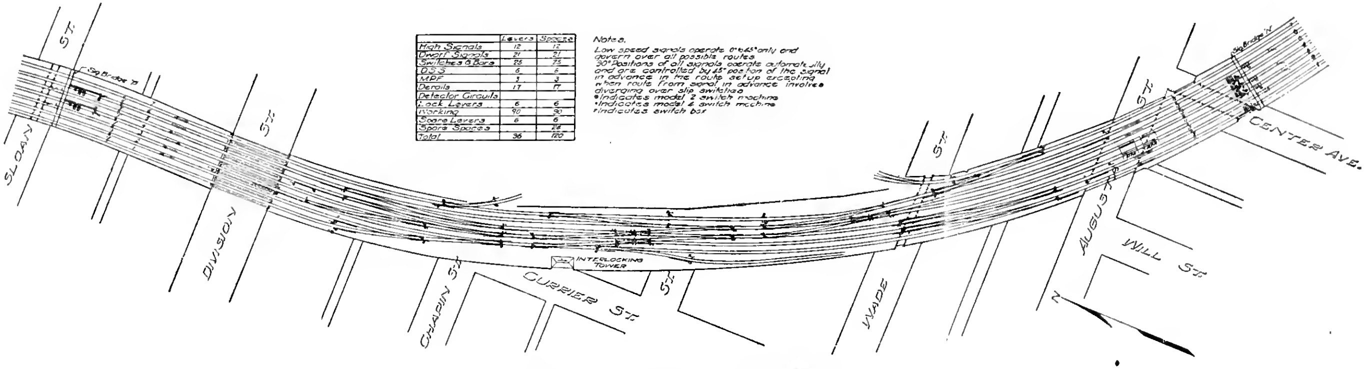




	Levers	Spaces
High Signals	10	10
Dwarf Signals	11	11
Derails & Bars	11	11
Switches & Bars	7	7
D.S.S. & Bars	8	8
M.P.F. & Bars	4	4
Detector Circuits	-	
Lock Levers	4	4
Working	55	55
Spare Levers	13	13
Spare Spaces		12
Total	68	80

Notes.
Low speed signals operate 0°-45° only and govern over all possible routes
90° Positions of all signals operate automatically and are controlled by 45° position of the signal in advance in route set up, excepting when route from signal in advance involves diverging over slip switches
● Indicates model 2 switch machine.
• Indicates model 4 switch machine
× Indicates switch box

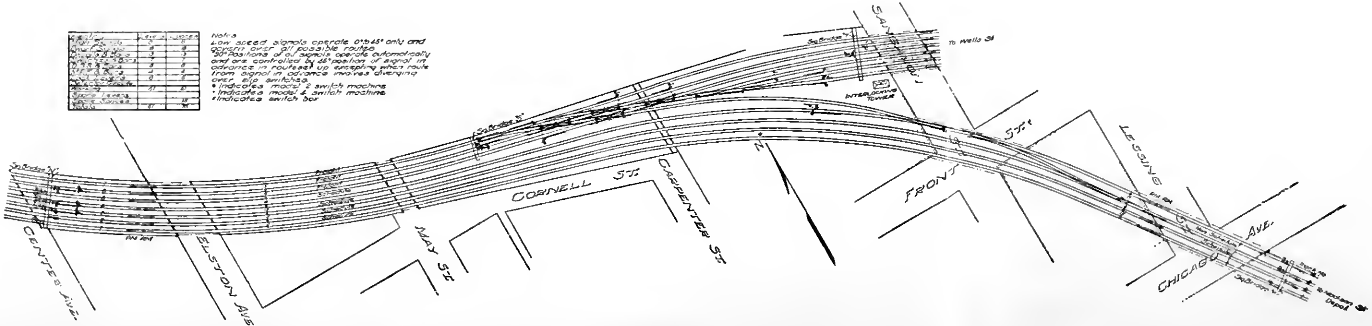
Noble Street Interlocking. Plate XVI—C.



	Levers	Spaces
High Signals	12	12
Dwarf Signals	21	21
Switches & Bars	25	25
D.S.S.	6	6
M.P.F.	3	3
Derails	17	17
Detector Circuits		
Lock Levers	6	6
Working	90	90
Spare Levers	6	6
Spare Spaces		24
Total	96	120

Notes.
Low speed signals operate 0° to 45° only and govern over all possible routes
90° Positions of all signals operate automatically and are controlled by 45° position of the signal in advance in the route set up excepting when route from signal in advance involves diverging over slip switches
● Indicates model 2 switch machine
• Indicates model 4 switch machine
× Indicates switch box

Division Street Interlocking. Plate XVI—D.



	Levers	Spaces
[illegible]	6	6
[illegible]	8	8
[illegible]	3	3
[illegible]	7	7
[illegible]	8	8
[illegible]	4	4
[illegible]	6	6
[illegible]		
Working	41	41
Spare Levers		
Spare Spaces		13
Total	47	[illegible]

Notes
Low speed signals operate 0° to 45° only and govern over all possible routes
90° Positions of all signals operate automatically and are controlled by 45° position of signal in advance in route set up excepting when route from signal in advance involves diverging over slip switches
● Indicates model 2 switch machine
• Indicates model 4 switch machine
× Indicates switch box

Carpenter Street Plant. Plate XVI—E.

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Plate XVIII.

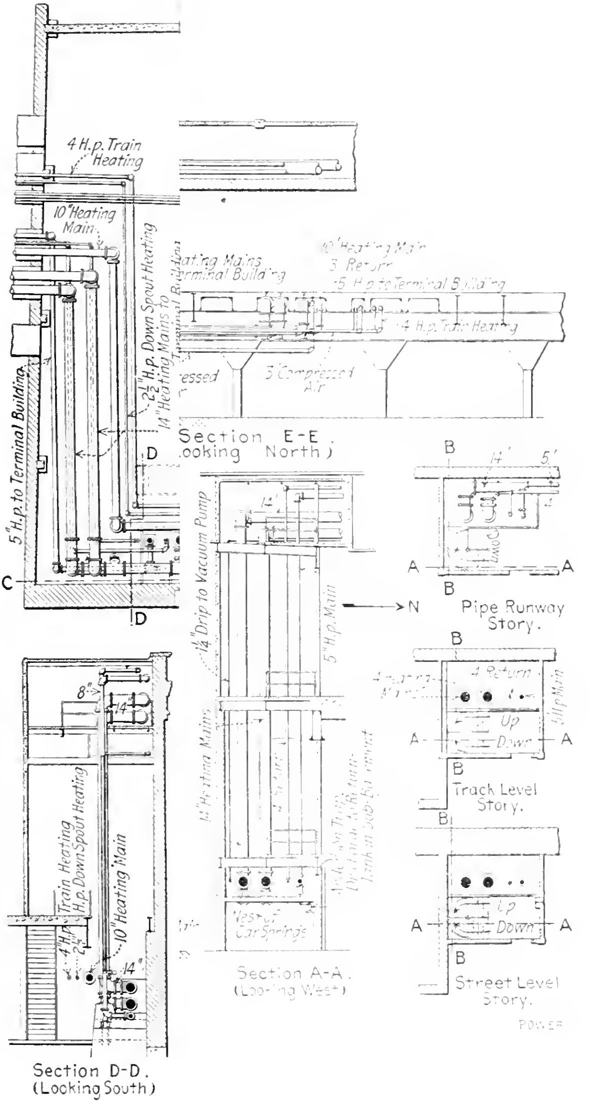

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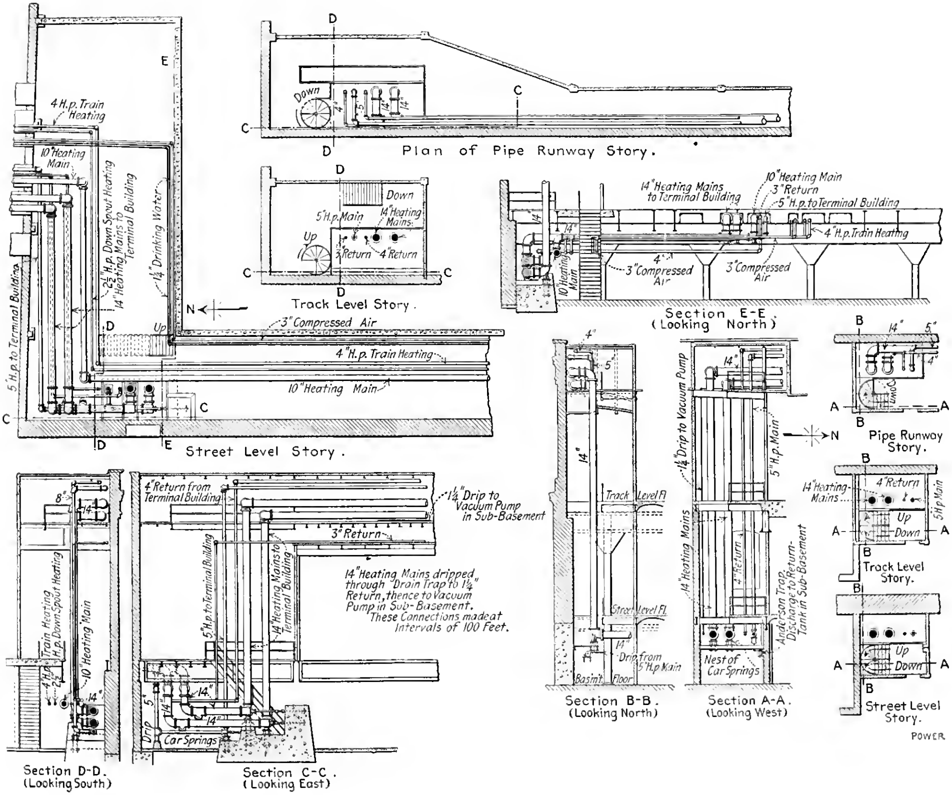
Plate XVIII.



POWER

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Plate XIX.

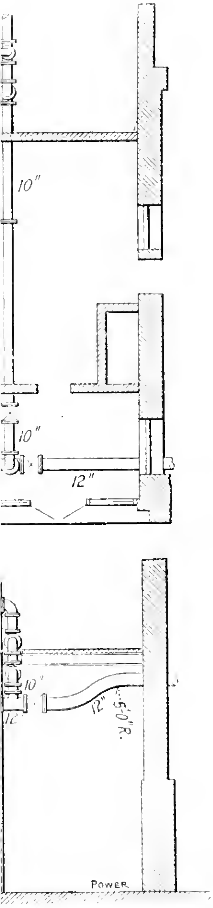
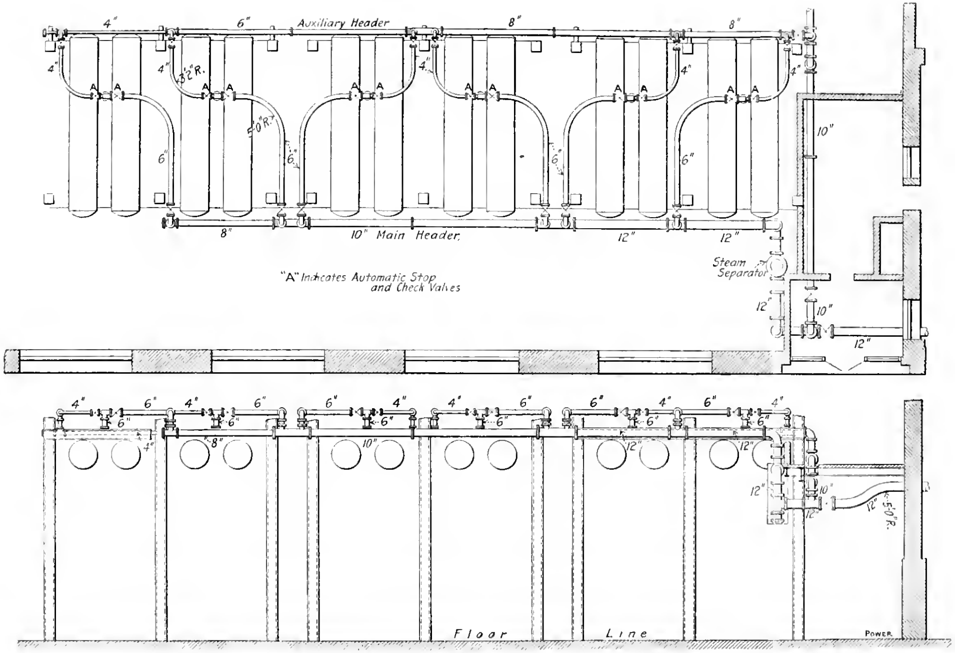


Plate XIX.



"A" Indicates Automatic Stop and Check Valves

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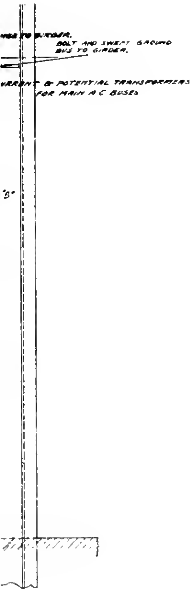
Plate XX.


TO GIRDER.
BOLT AND SWEAT GROUND BUS TO GIRDER.
URRENT & POTENTIAL TRANSFORMERS FOR MAIN A C BUSES
"5"

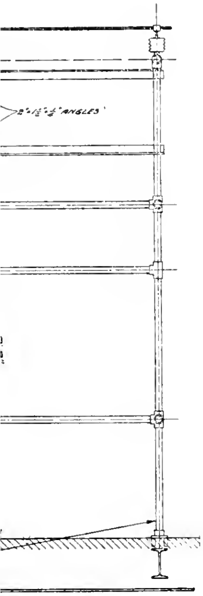


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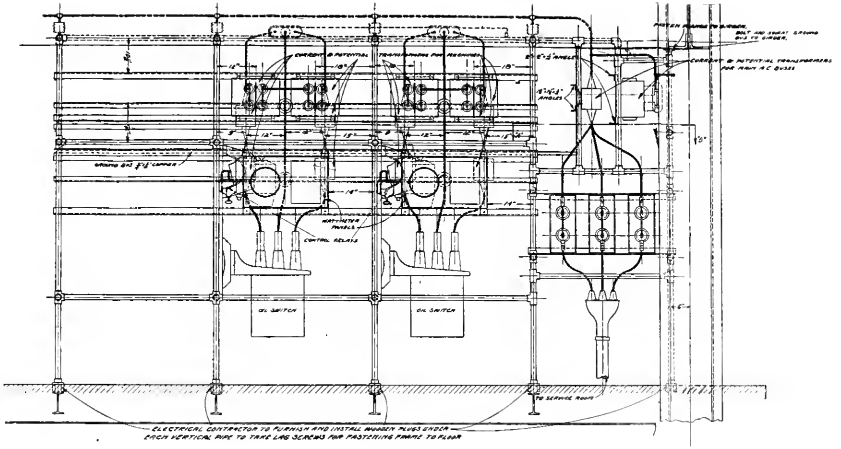
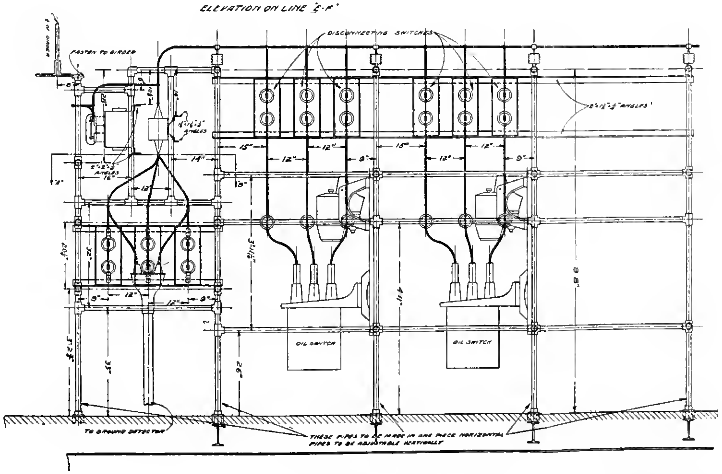
Plate XX.


CURRENT & POTENTIAL TRANSFORMERS FOR MACHINES
FASTEN FRAME TO GIRDER
BOLT AND SWEAT GROUND BUS TO GIRDER
CURRENT & POTENTIAL TRANSFORMERS FOR MAIN A.C. BUSES
2"×2"×¼" ANGLE
1½"×1½"×¼" ANGLES
GROUND BUS ⅜"×1½" COPPER
WATTMETER PANELS
CONTROL RELAYS
OIL SWITCH
OIL SWITCH
TO SERVICE ROOM
12"
18"
15"
9"
12"
15"
14"
6"
ELECTRICAL CONTRACTOR TO FURNISH AND INSTALL WOODEN PLUGS UNDER EACH VERTICAL PIPE TO TAKE LAG SCREWS FOR FASTENING FRAME TO FLOOR

ELEVATION ON LINE "E-F"



ELEVATION ON LINE "G-H"

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Plate XXI.

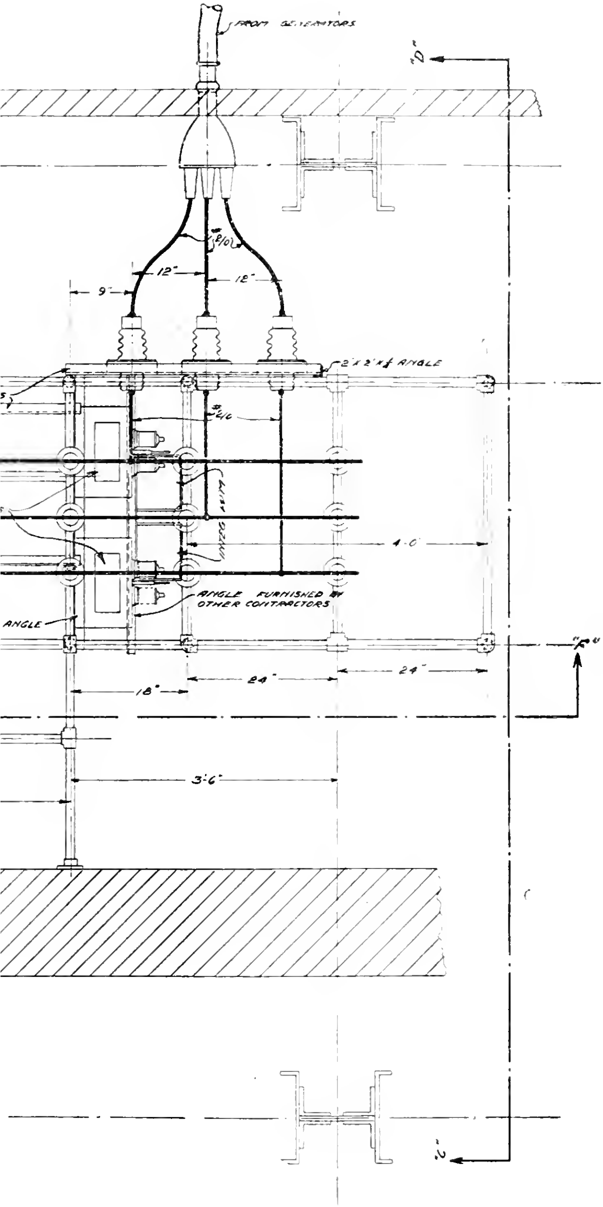

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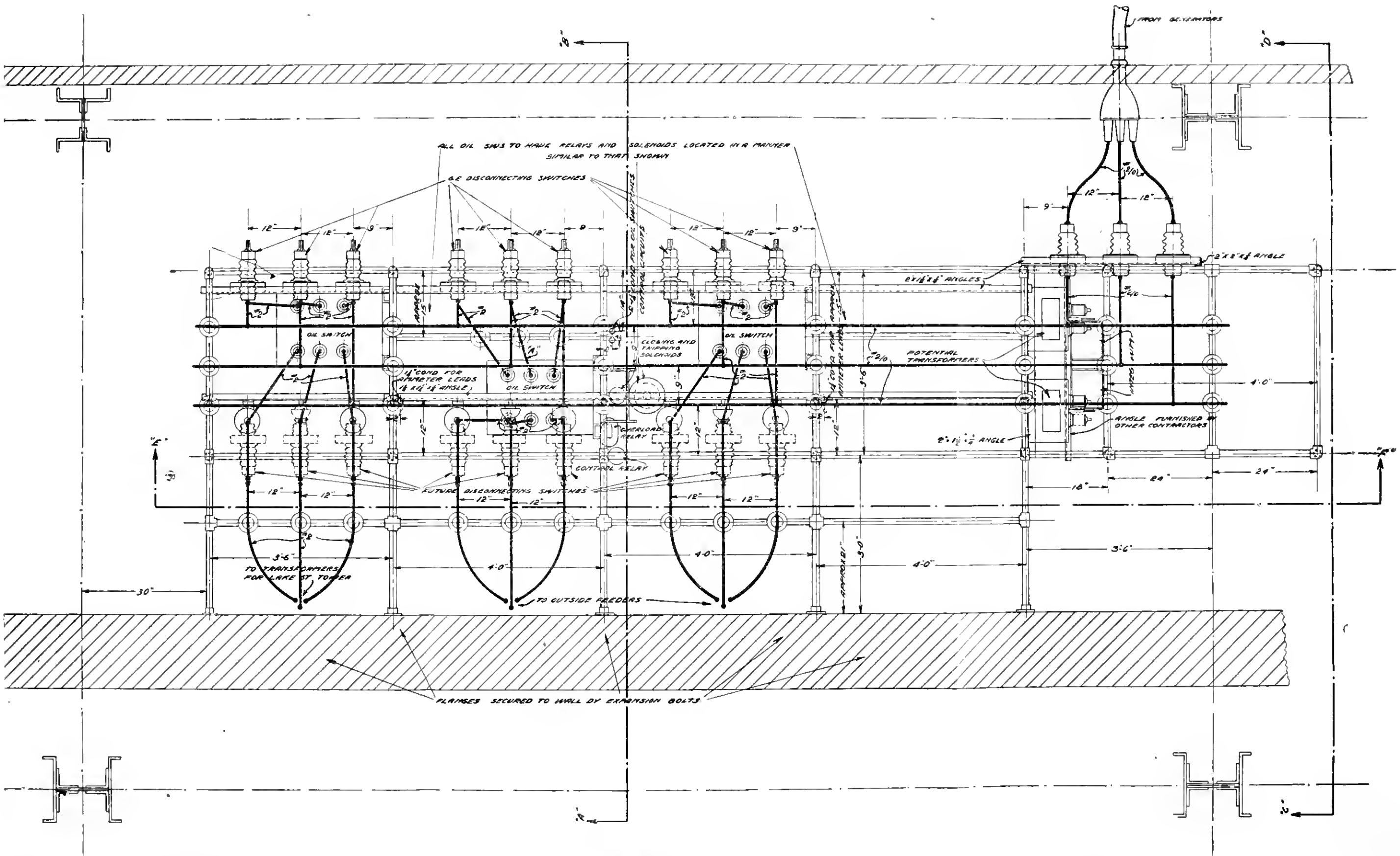
Plate XXI.


FROM GENERATORS
"D"
"B"
"A"
"C"
"E"
"F"
ALL OIL SWS TO HAVE RELAYS AND SOLENOIDS LOCATED IN A MANNER SIMILAR TO THAT SHOWN
G.E DISCONNECTING SWITCHES
12"
9"
APPROX 15"
#2
"A"
OIL SWITCH
1¼" COND FOR OIL SWITCHES CONTROL CIRCUITS
CLOSING AND TRIPPING SOLENOIDS
1¼" COND FOR AMMETER LEADS
1¼ x 1¼ x ¼ ANGLE
9"
3'-6"
#2/0
#4/0
2" x 2" x ¼ ANGLE
2 x 1½ x ¼ ANGLES
POTENTIAL TRANSFORMERS
4'-0"
ANGLE FURNISHED BY OTHER CONTRACTORS
2 x 1½ x ¼ ANGLE
OVERLOAD RELAY
CONTROL RELAY
FUTURE DISCONNECTING SWITCHES
18"
24"
3'-0"
APPROX 21"
30"
TO TRANSFORMERS FOR LAKE ST. TOWER
TO OUTSIDE FEEDERS
FLANGES SECURED TO WALL BY EXPANSION BOLTS

PLAN

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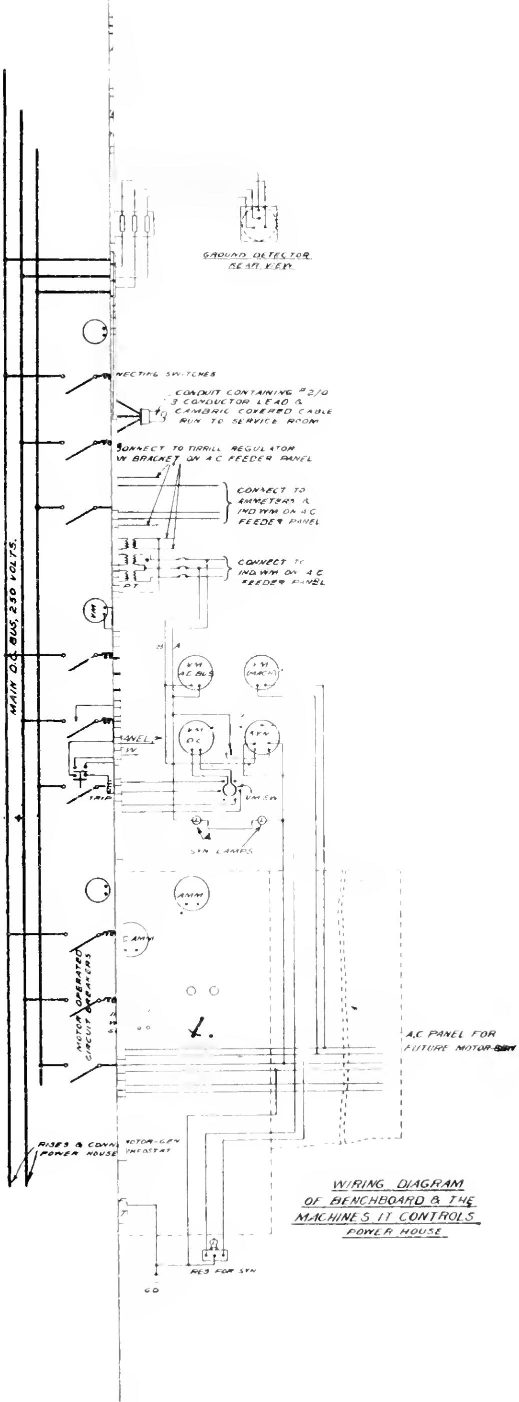
Plate XXII.



WIRING DIAGRAM
OF BENCHBOARD & THE
MACHINES IT CONTROLS
POWER HOUSE

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Plate XXII

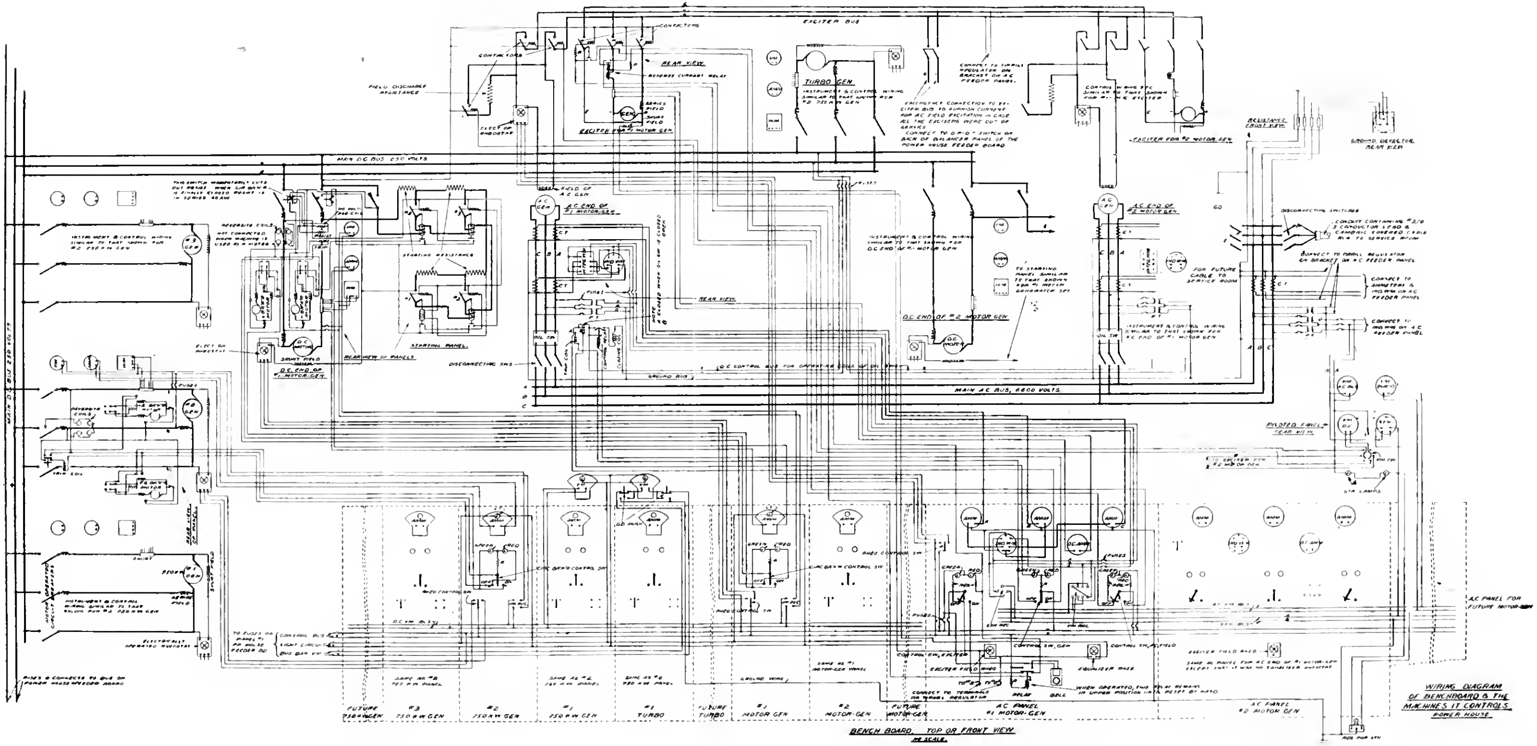

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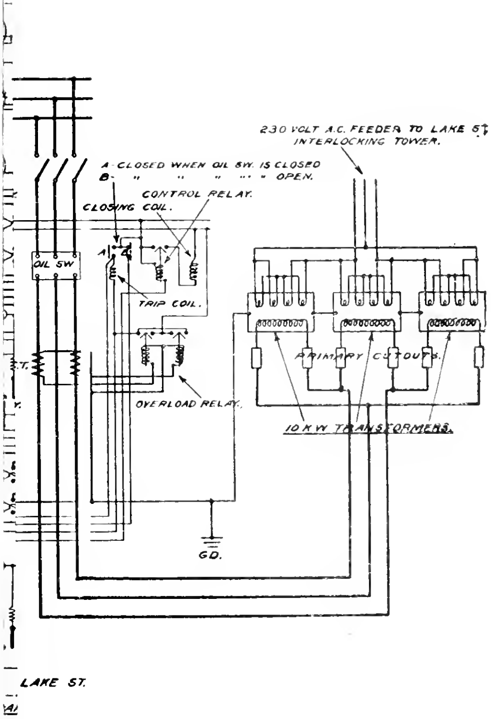
Plate XXIII



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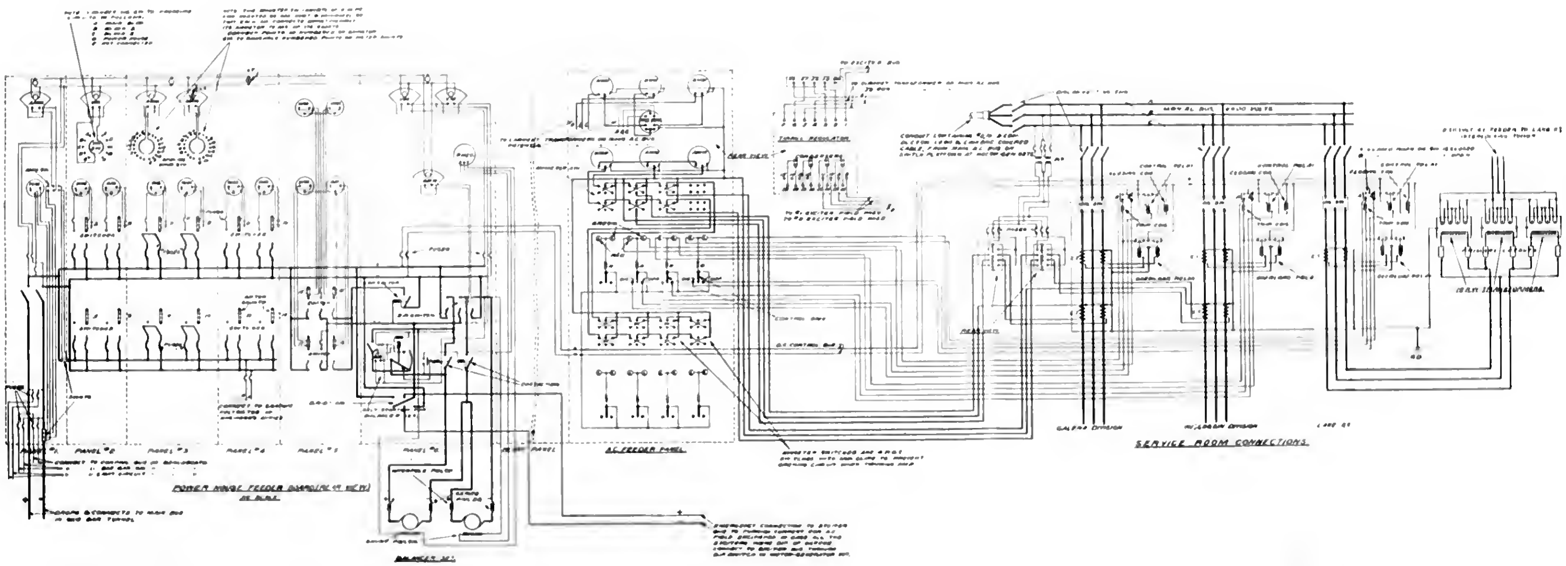

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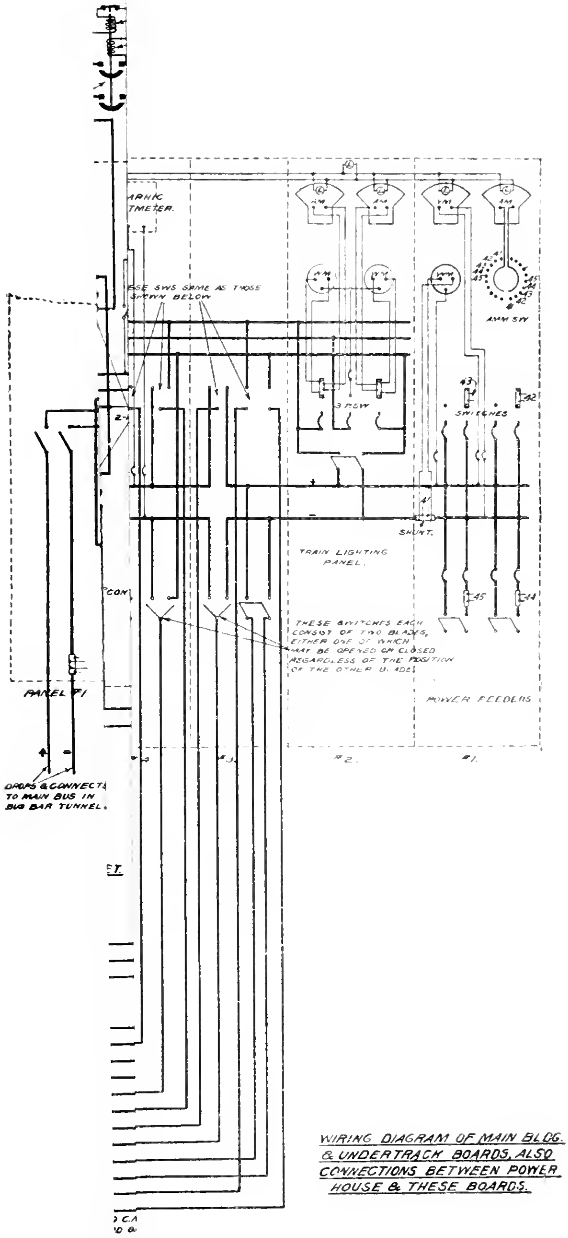
Plate XXIV.


APHIC
TMETER.
ESE SWS SAME AS THOSE SHOWN BELOW
VM
AM
AM
VM
AM
VM
VM
VM
41
42
43
44
45
AMM SW
43
42
3 P.S.W
SWITCHES
+
−
41
SHUNT.
45
44
CON
TRAIN LIGHTING PANEL.
THESE SWITCHES EACH CONSIST OF TWO BLADES, EITHER ONE OF WHICH MAY BE OPENED OR CLOSED REGARDLESS OF THE POSITION OF THE OTHER BLADE.
POWER FEEDERS
PANEL #1
#4
#3
#2
#1
+
−
DROPS & CONNECTS TO MAIN BUS IN BUS BAR TUNNEL.
ET.
C.A
D &

WIRING DIAGRAM OF MAIN BLDG. & UNDERTRACK BOARDS, ALSO CONNECTIONS BETWEEN POWER HOUSE & THESE BOARDS.

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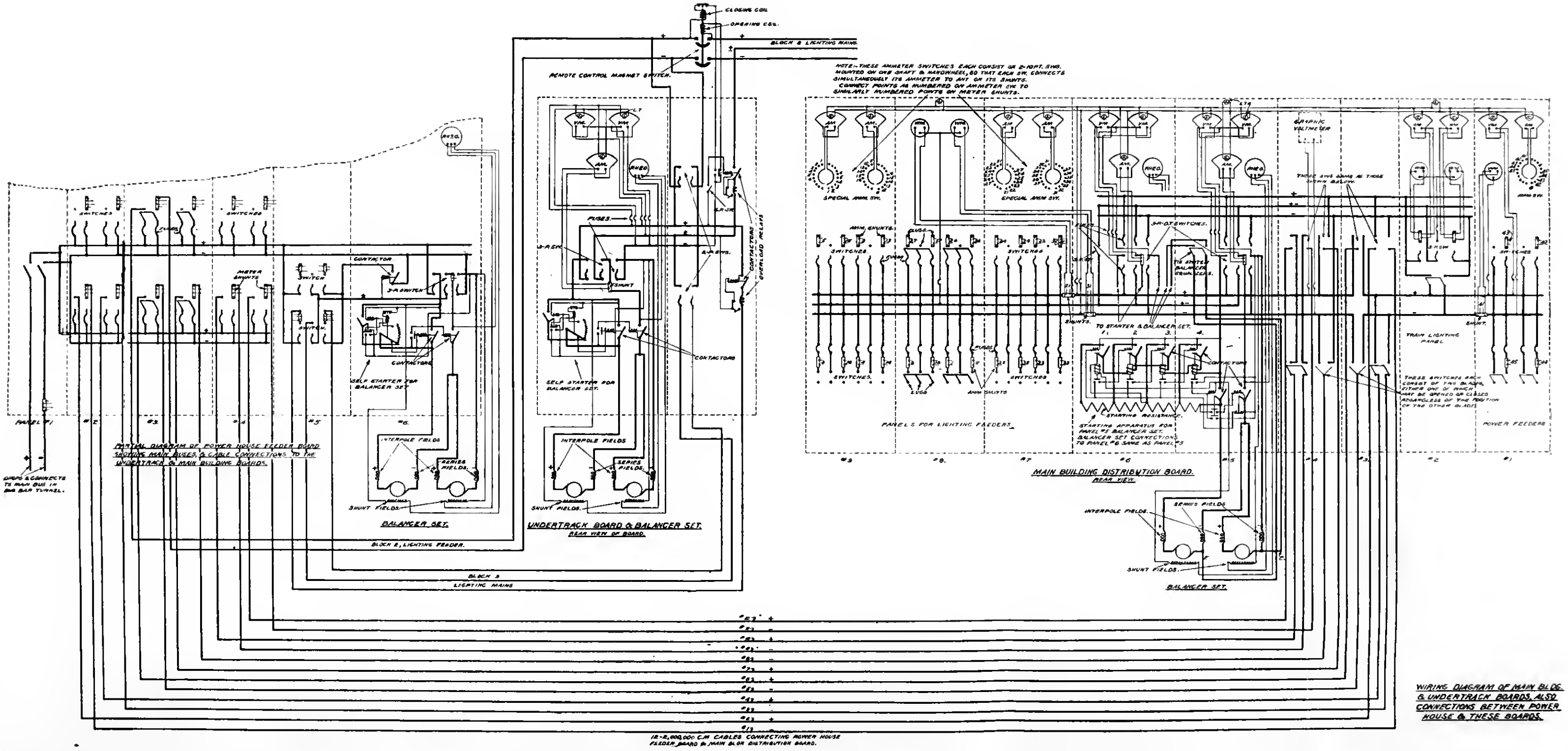
Plate XXIV.


CLOSING COIL
OPENING COIL
BLOCK 8 LIGHTING MAINS
REMOTE CONTROL MAGNET SWITCH.
NOTE:—THESE AMMETER SWITCHES EACH CONSIST OF 2-10PT. SWS. MOUNTED ON ONE SHAFT & HANDWHEEL, SO THAT EACH SW. CONNECTS SIMULTANEOUSLY ITS AMMETER TO ANY OF ITS SHUNTS. CONNECT POINTS AS NUMBERED ON AMMETER SW. TO SIMILARLY NUMBERED POINTS ON METER SHUNTS.
RHEO.
SWITCHES
FUSES
METER SHUNTS
SWITCH
CONTACTOR
3-P. SWITCH
CONTACTORS
SELF STARTER FOR BALANCER SET
PANEL #1
#2
#3
#4
#5
#6.
PARTIAL DIAGRAM OF POWER HOUSE FEEDER BOARD SHOWING MAIN BUSES & CABLE CONNECTIONS TO THE UNDERTRACK & MAIN BUILDING BOARDS.
DROPS & CONNECTS TO MAIN BUS IN BUS BAR TUNNEL.
INTERPOLE FIELDS
SERIES FIELDS.
SHUNT FIELDS.
BALANCER SET.
BLOCK 2, LIGHTING FEEDER.
VM.
AM.
FUSES.
3-P. SW.
SHUNT
S.P. SW.
A.P. SWS.
CONTACTORS
OVERLOAD RELAYS
SELF STARTER FOR BALANCER SET.
UNDERTRACK BOARD & BALANCER SET.
REAR VIEW OF BOARD.
BLOCK 3
LIGHTING MAINS
SPECIAL AMM. SW.
AMM. SHUNTS.
PLUGS
FUSE
SHUNTS.
3-P.-D.T. SWITCHES.
TIE SWITCH BALANCER EQUALIZERS.
TO STARTER & BALANCER SET.
1. 2. 3. 4.
GRAPHIC VOLTMETER
THESE SWS. SAME AS THOSE SHOWN BELOW.
LUGS
AMM SHUNTS
STARTING RESISTANCE.
STARTING APPARATUS FOR PANEL #5 BALANCER SET. BALANCER SET CONNECTIONS TO PANEL #6 SAME AS PANEL #5
PANELS FOR LIGHTING FEEDERS.
TRAIN LIGHTING PANEL
SHUNT.
AMM. SW.
THESE SWITCHES EACH CONSIST OF TWO BLADES, EITHER ONE OF WHICH MAY BE OPENED OR CLOSED REGARDLESS OF THE POSITION OF THE OTHER BLADE.
POWER FEEDERS
#9 #8 #7 #6 #5 #4 #3 #2 #1
MAIN BUILDING DISTRIBUTION BOARD.
REAR VIEW.
12-2,000,000 C.M. CABLES CONNECTING POWER HOUSE FEEDER BOARD & MAIN BLDG. DISTRIBUTION BOARD.

WIRING DIAGRAM OF MAIN BLDG. & UNDERTRACK BOARDS, ALSO CONNECTIONS BETWEEN POWER HOUSE & THESE BOARDS.

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